NLP and Word Embeddings

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Word representation

Word representation

V = [a, aaron, ..., zulu, <UNK>]

$|V| = 10{,}000$

1-hot representation

$$
\begin{array}{cccccc}
\text{Man} & \text{Woman} & \text{King} & \text{Queen} & \text{Apple} & \text{Orange} \\
(5391) & (9853) & (4914) & (7157) & (456) & (6257) \\
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \\ 0 \end{bmatrix} &
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{bmatrix} &
\begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \\ 0 \\ 0 \end{bmatrix} &
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{bmatrix} &
\begin{bmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} &
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{bmatrix} \\
O_{5391} & O_{9853} & & & &
\end{array}
$$

I want a glass of orange juice.

I want a glass of apple ? .

Featurized representation: word embedding

	Man (5391)	Woman (9853)	King (4914)	Queen (7157)	Apple (456)	Orange (6257)
Gender	-1	1	-0.95	0.97	0.00	0.01
Royal	0.01	0.02	0.93	0.95	-0.01	0.00
Age	0.03	0.02	0.7	0.69	0.03	-0.02
Food	0.04	0.01	0.02	0.01	0.95	0.97
⋮	⋮	⋮				
	e_{5391}	e_{9853}				

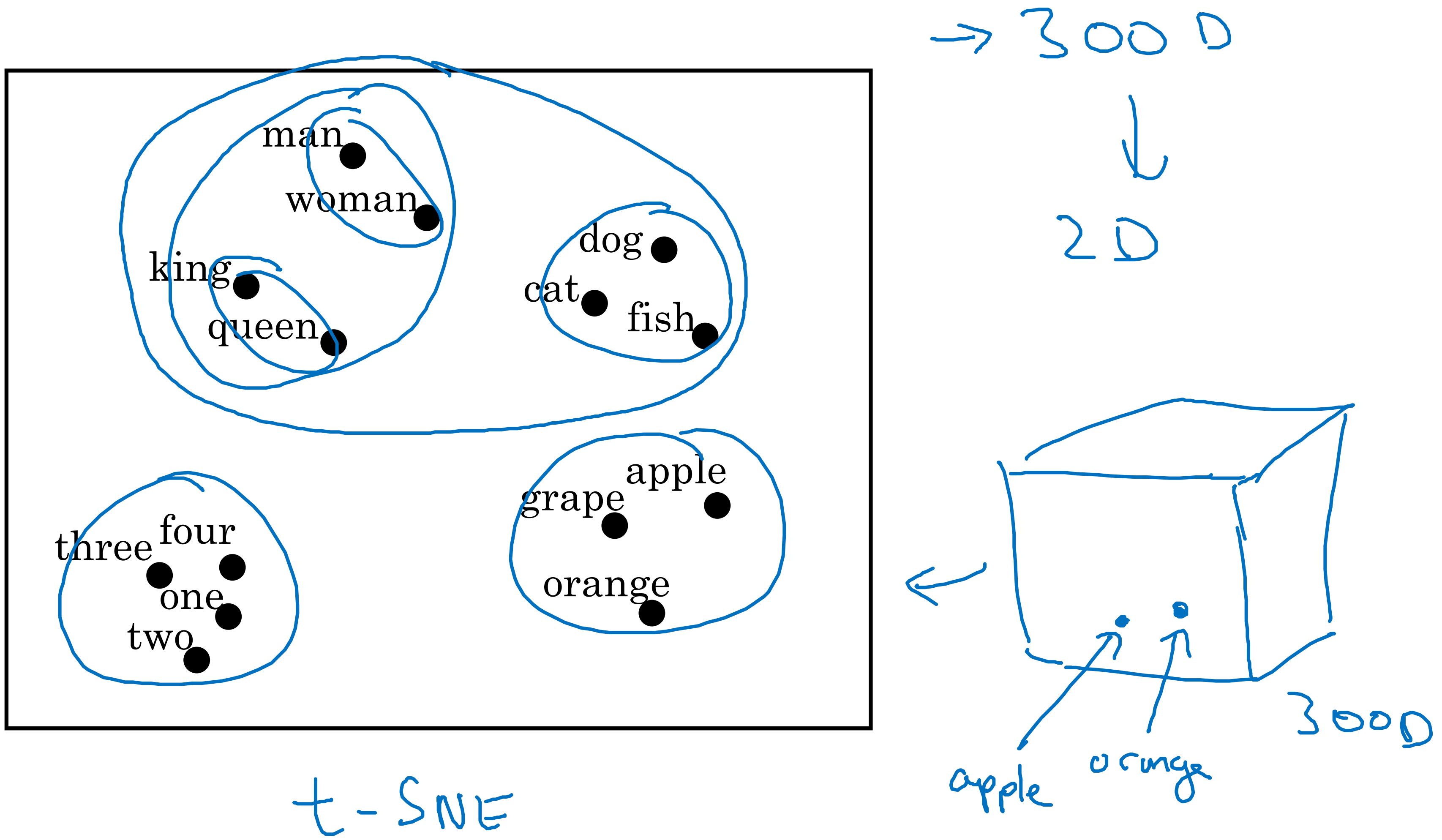
300

size
cost
alive
verb

I want a glass of orange juice.

I want a glass of apple juice.

Visualizing word embeddings



[van der Maaten and Hinton., 2008. Visualizing data using t-SNE]

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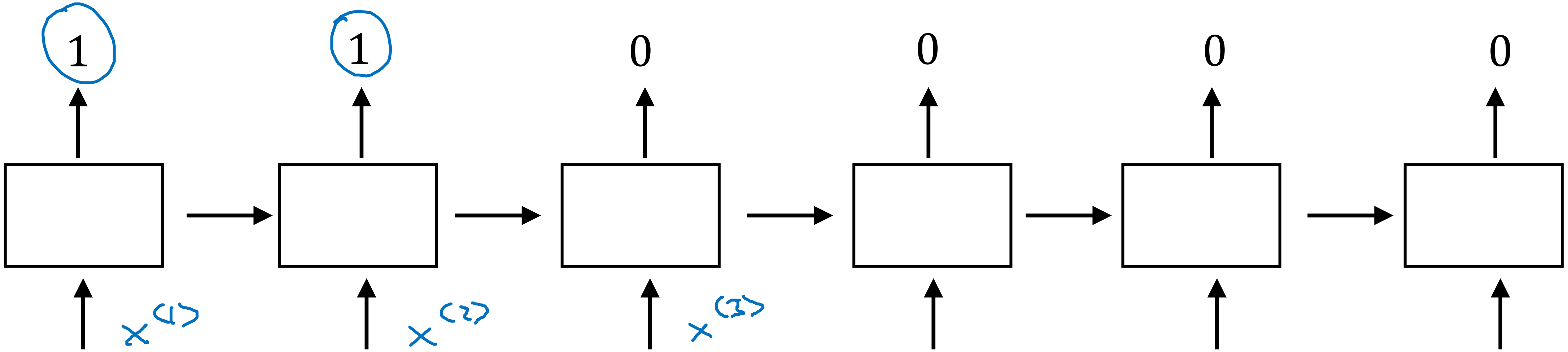
Using word embeddings

Named entity recognition example



Sally Johnson is an orange farmer

Robert Lin is ~~an~~ ~~apple farmer~~

→ 1B words – 100B words

a

durian

cultivator.

→ 100k words

BRNN

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Transfer learning and word embeddings

A

1. Learn word embeddings from large text corpus. (1-100B words)

   (Or download pre-trained embedding online.)

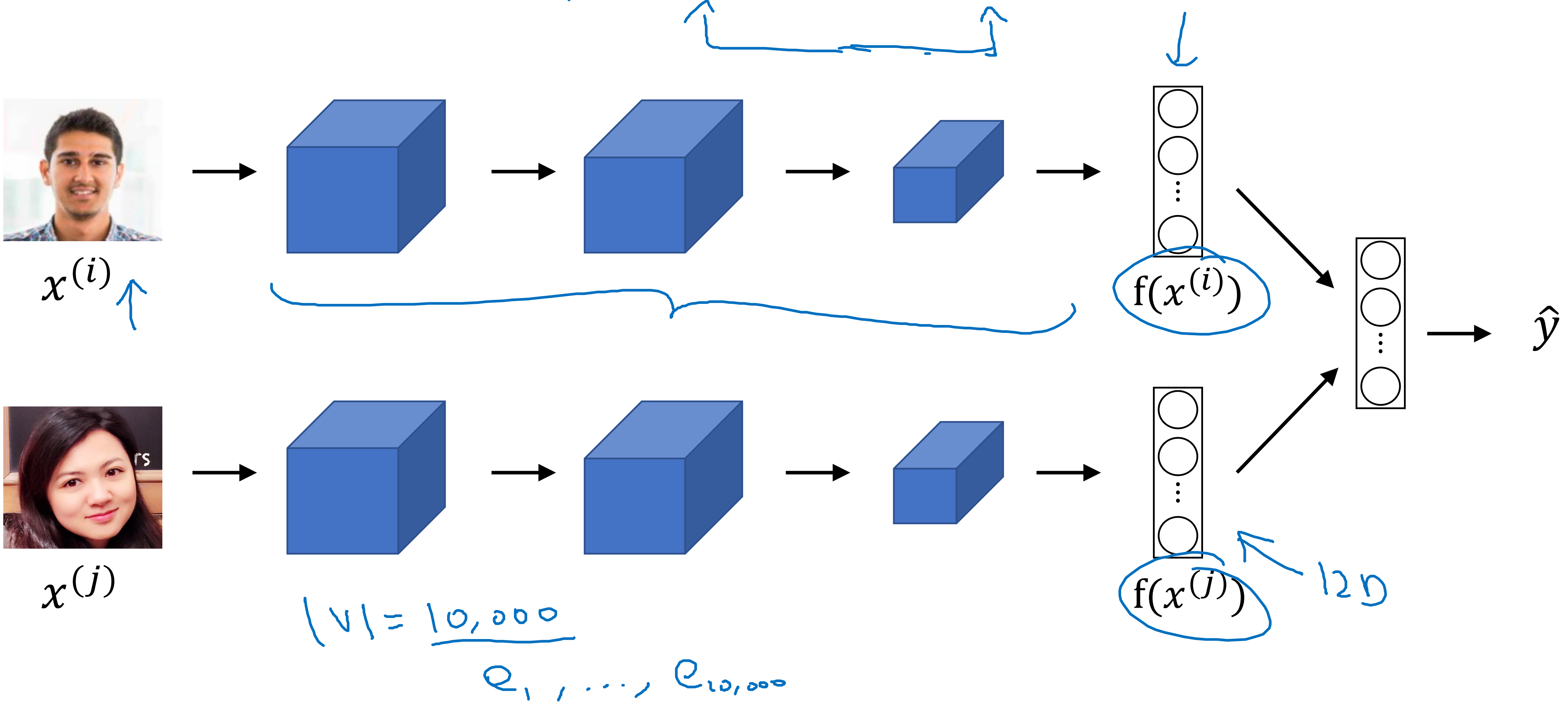
B

2. Transfer embedding to new task with smaller training set. (say, 100k words)

   → 10,000 → 300

3. Optional: Continue to finetune the word embeddings with new data.

Relation to face encoding (embedding)



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Properties of word embeddings

Analogies

	Man (5391)	Woman (9853)	King (4914)	Queen (7157)	Apple (456)	Orange (6257)
Gender	−1	1	-0.95	0.97	0.00	0.01
Royal	0.01	0.02	0.93	0.95	-0.01	0.00
Age	0.03	0.02	0.70	0.69	0.03	-0.02
Food	0.09	0.01	0.02	0.01	0.95	0.97

e_{5391}

e_{man} $\quad e_{woman}$

Man → Woman as King →? Queen

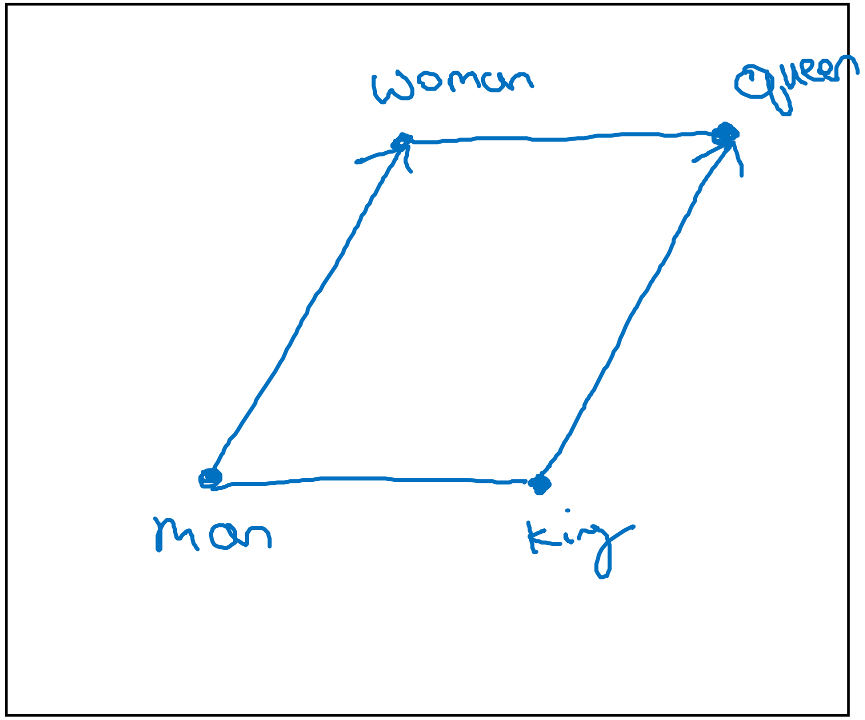
$e_{man} - e_{woman} \approx e_{king} - e_{?}$ ← queen

$e_{man} - e_{woman} \approx \begin{bmatrix} -2 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

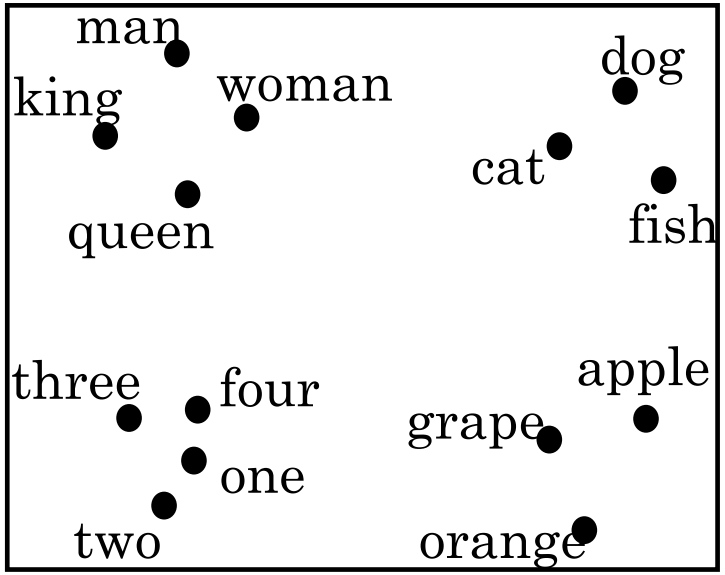
$e_{king} - e_{queen} \approx \begin{bmatrix} -2 \\ 0 \\ 0 \\ 0 \end{bmatrix}$

[Mikolov et. al., 2013, Linguistic regularities in continuous space word representations]

Analogies using word vectors



300 D



300D → 2D

t-SNE

$$e_{man} - e_{woman} \approx e_{king} - \cancel{e_?}\ e_w$$

Find word w: $\arg\max_{w}\ \boxed{sim(e_w, e_{king} - e_{man} + e_{woman})}$

30 – 75%

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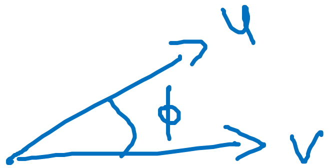
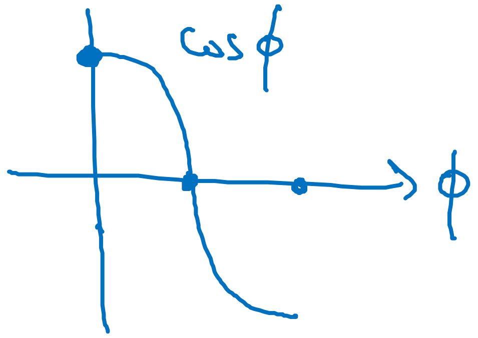
Cosine similarity

$$\boxed{sim(e_w, e_{king} - e_{man} + e_{woman})}$$

$$\underline{sim(u,v)} = \frac{u^T v}{\|u\|_2 \|v\|_2}$$





$$\|u - v\|^2$$

Man:Woman as Boy:Girl

Ottawa:Canada as Nairobi:Kenya

Big:Bigger as Tall:Taller

Yen:Japan as Ruble:Russia

NLP and Word Embeddings

Embedding matrix

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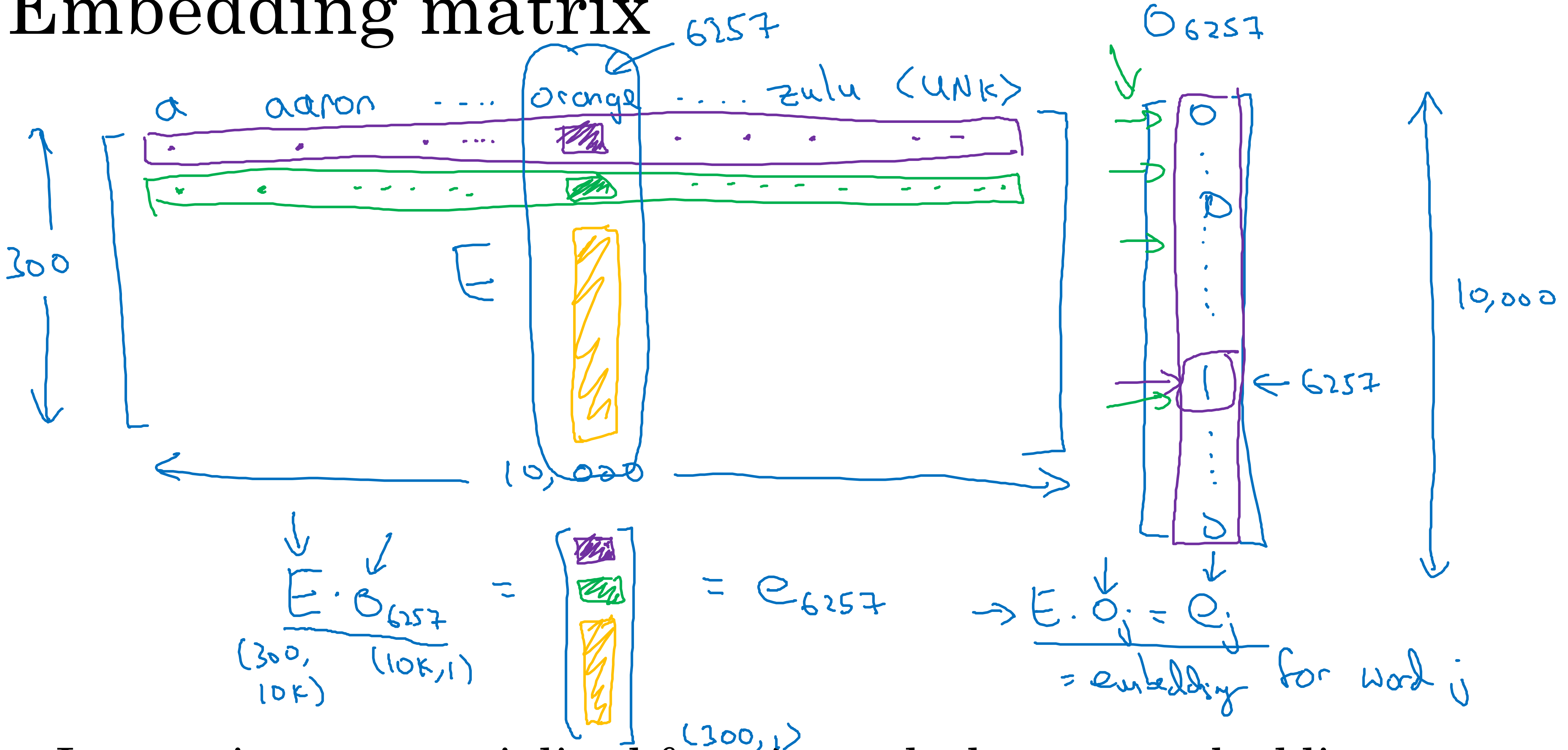
Embedding matrix



In practice, use specialized function to look up an embedding.

→ Embedding

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NLP and Word Embeddings

Learning word embeddings

Neural language model

4

I	want	a	glass	of	orange	______.
4343	9665	1	3852	6163	6257	juice

apple ~~juice~~ juice.

$e_{4343} = E\, o_{4343}$

~~I $\quad o_{4343} \longrightarrow E \longrightarrow e_{4343}$~~

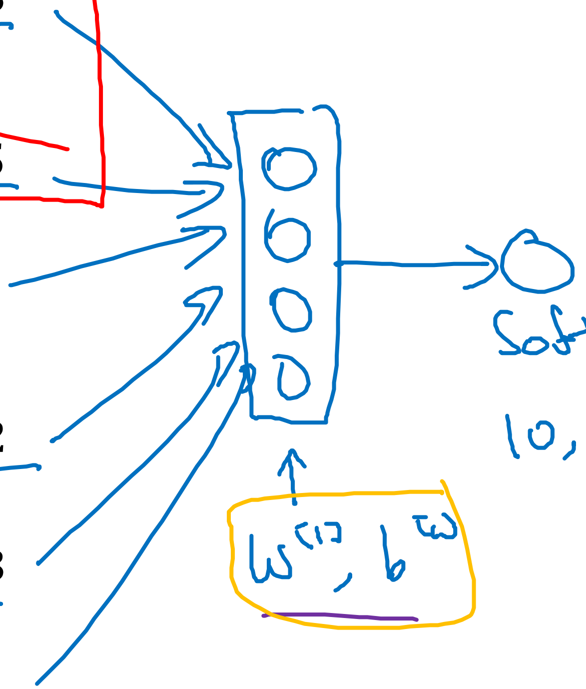
~~want $\quad o_{9665} \longrightarrow E \longrightarrow e_{9665}$~~

a $\quad o_{1} \longrightarrow E \longrightarrow e_{1}$

glass $\quad o_{3852} \longrightarrow E \longrightarrow e_{3852}$

of $\quad o_{6163} \longrightarrow E \longrightarrow e_{6163}$

orange $\quad o_{6257} \longrightarrow E \longrightarrow e_{6257}$



Softmax

10,000

$W^{[1]}, b^{[1]}$

$W^{[2]}, b^{[2]}$

~~1800~~ 1200

[Bengio et. al., 2003, A neural probabilistic language model]

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Other context/target pairs

I want a glass of orange juice to go along with my cereal.

context

target

Context: Last 4 words.

4 words on left & right

Last 1 word

Nearby 1 word

skip gram

a glass of orange ? to go along with

orange ?

glass ?

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Word2Vec

Skip-grams

I want a glass of orange juice to go along with my cereal.

Context	Target
orange	juice
orange	glass
orange	my

[Mikolov et. al., 2013. Efficient estimation of word representations in vector space.]

Model

Vocab size = 10,000k

x ⟶ y

Context c ("orange") 6257 ⟶ Target t ("juice") 4834

$$O_c \rightarrow E \rightarrow e_c \rightarrow \underset{\text{softmax}}{O} \rightarrow \hat{y}$$

$$e_c = E O_c$$

Softmax: $p(t|c) = \dfrac{e^{\theta_t^T e_c}}{\sum_{j=1}^{10,000} e^{\theta_j^T e_c}}$

θ_t = parameter associated with output t

$$\rightarrow \mathcal{L}(\hat{y}, y) = -\sum_{i=1}^{10,000} y_i \log \hat{y}_i$$

$$y = \begin{bmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{bmatrix} \leftarrow 4834$$

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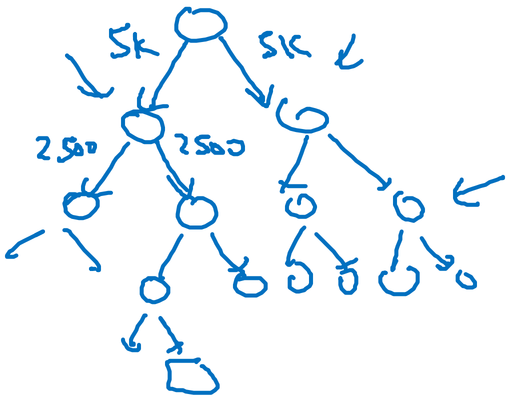
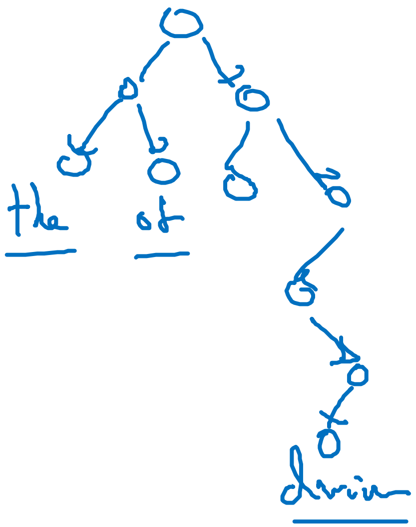
Problems with softmax classification

$$p(t|c) = \frac{e^{\theta_t^T e_c}}{\boxed{\sum_{j=1}^{10,000} e^{\theta_j^T e_c}}}$$

Hierarchical softmax.

$\log |V|$





How to sample the context c?

t

→ the, of, a, and, to, ...

$c \rightarrow t$

→ orange, apple, durian

$P(c)$

e_{durian}

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NLP and Word Embeddings

Negative sampling

Defining a new learning problem

I want a glass of orange juice to go along with my cereal.

x → y

Context	word	target?
orange	juice	1
orange	king	0
orange	book	0
orange	the	0
orange	of	0

k

k = 5-20 smaller datasets

k = 2-5 larger dataset

[Mikolov et. al., 2013. Distributed representation of words and phrases and their compositionality]

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Model

Softmax: $p(t|c) = \frac{e^{\theta_t^T e_c}}{\sum_{j=1}^{10,000} e^{\theta_j^T e_c}}$

10,000-way softmax

$P(y=1 \mid c, t) = \sigma(\theta_t^T e_c)$

context	word	target?
orange	juice	1
orange	king	0
orange	book	0
orange	the	0
orange	of	0

x y

k

c t y

Orange 6257

$O_{6257} \rightarrow E \rightarrow e_{6257}$

juice?

king

10,000

10,000 binary classification problem

k+1

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Selecting negative examples

$\underbrace{\text{context} \quad \text{word}}_{x}$		$\underbrace{\text{target?}}_{y}$
orange	juice	1
orange	king	0
orange	book	0
orange	the	0
orange	of	0

t

the , of, and, ...

$$P(w_i) = \frac{f(w_i)^{3/4}}{\sum_{j=1}^{10,000} f(w_j)^{3/4}}$$

$$\frac{1}{|V|}$$

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GloVe word vectors

GloVe (global vectors for word representation)

I want a glass of orange juice to go along with my cereal.

c, t

X_{ij} = # times i appears in context of j.

$i \leftarrow t$, $j \leftarrow c$ (in X_{ij}: $i \leftarrow c$, $j \leftarrow t$)

$X_{ij} = X_{ji}$

[Pennington et. al., 2014. GloVe: Global vectors for word representation]

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Model

$$\text{minimize} \sum_{i=1}^{10,000} \sum_{j=1}^{10,000} \underbrace{f(X_{ij})}_{\text{weighting term}} (\theta_i^T e_j + b_i + b_j' - \log X_{ij})^2$$

t c

"$\theta_t^T e_c$"

$\log X_{ij} \to 0$?

$f(X_{ij}) = 0$ if $X_{ij} = 0$. "$0 \log 0$" $= 0$

this, is, of, a, ...

durian

θ_i, e_j are symmetric

$$e_w^{(final)} = \frac{e_w + \theta_w}{2}$$

A note on the featurization view of word embeddings

	Man (5391)	Woman (9853)	King (4914)	Queen (7157)
Gender	−1	1	-0.95	0.97
Royal	0.01	0.02	0.93	0.95
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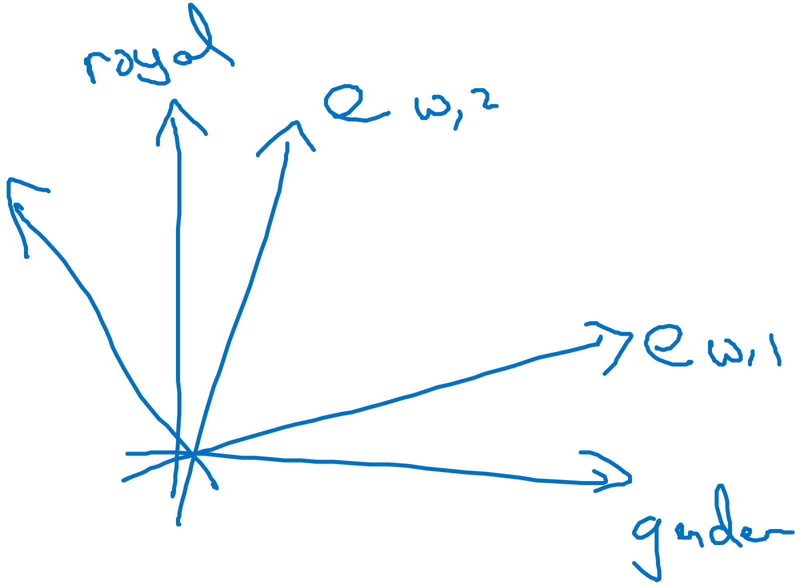
Food	0.09	0.01	0.02	0.01



$$\text{minimize} \sum_{i=1}^{10,000} \sum_{j=1}^{10,000} f(X_{ij})\left(\theta_i^T e_j + b_i - b_j' - \log X_{ij}\right)^2$$

$$(A\theta_i)^T (A^{-T} e_j) = \theta_i^T \cancel{A^T} \cancel{A^{-T}} e_j$$

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NLP and Word Embeddings

Sentiment classification

Sentiment classification problem

$x \longrightarrow y$

The dessert is excellent.	★★★★☆
Service was quite slow.	★★☆☆☆
Good for a quick meal, but nothing special.	★★★☆☆
Completely lacking in good taste, good service, and good ambience.	★☆☆☆☆

10,000 → 100,000 words

Simple sentiment classification model

The dessert is excellent ★★★★☆

8928 2468 4694 3180

The $o_{8928} \longrightarrow E \longrightarrow e_{8928}$

desert $o_{2468} \longrightarrow E \longrightarrow e_{2468}$

is $o_{4694} \longrightarrow E \longrightarrow e_{4694}$

excellent $o_{3180} \longrightarrow E \longrightarrow e_{3180}$

$\underbrace{e_{3180}}_{300D}$

$\boxed{\text{Avg}} \longrightarrow o \longrightarrow \hat{y}$

300D

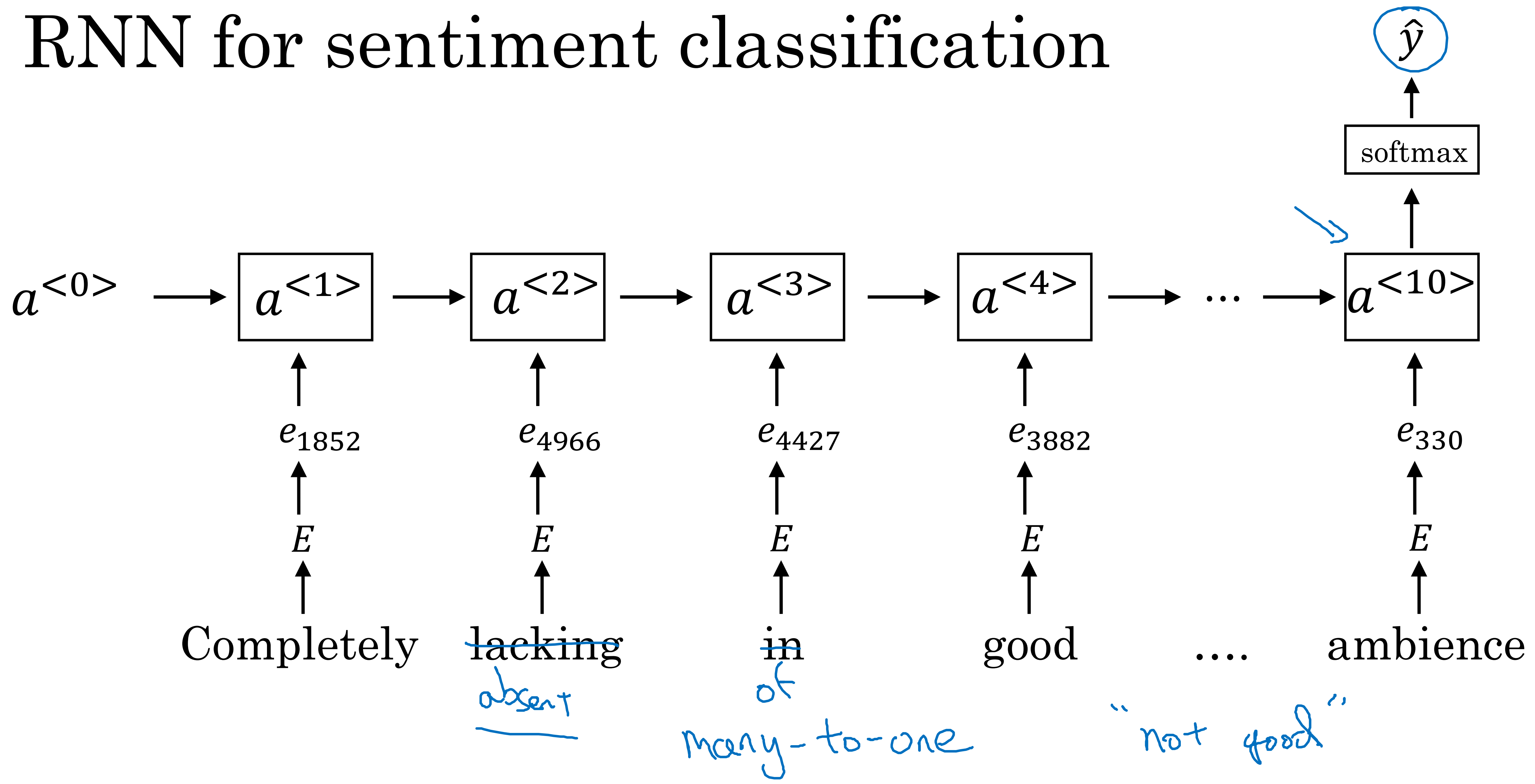
softmax

1-5

100B words

"Completely lacking in $\boxed{\text{good}}$ taste, $\boxed{\text{good}}$ service, and $\boxed{\text{good}}$ ambience."

RNN for sentiment classification



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NLP and Word Embeddings

Debiasing word embeddings

The problem of bias in word embeddings

Man:Woman as King:Queen

Man:Computer_Programmer as Woman: Homemaker

Father:Doctor as Mother: Nurse

Word embeddings can reflect gender, ethnicity, age, sexual orientation, and other biases of the text used to train the model.

[Bolukbasi et. al., 2016. Man is to computer programmer as woman is to homemaker? Debiasing word embeddings]

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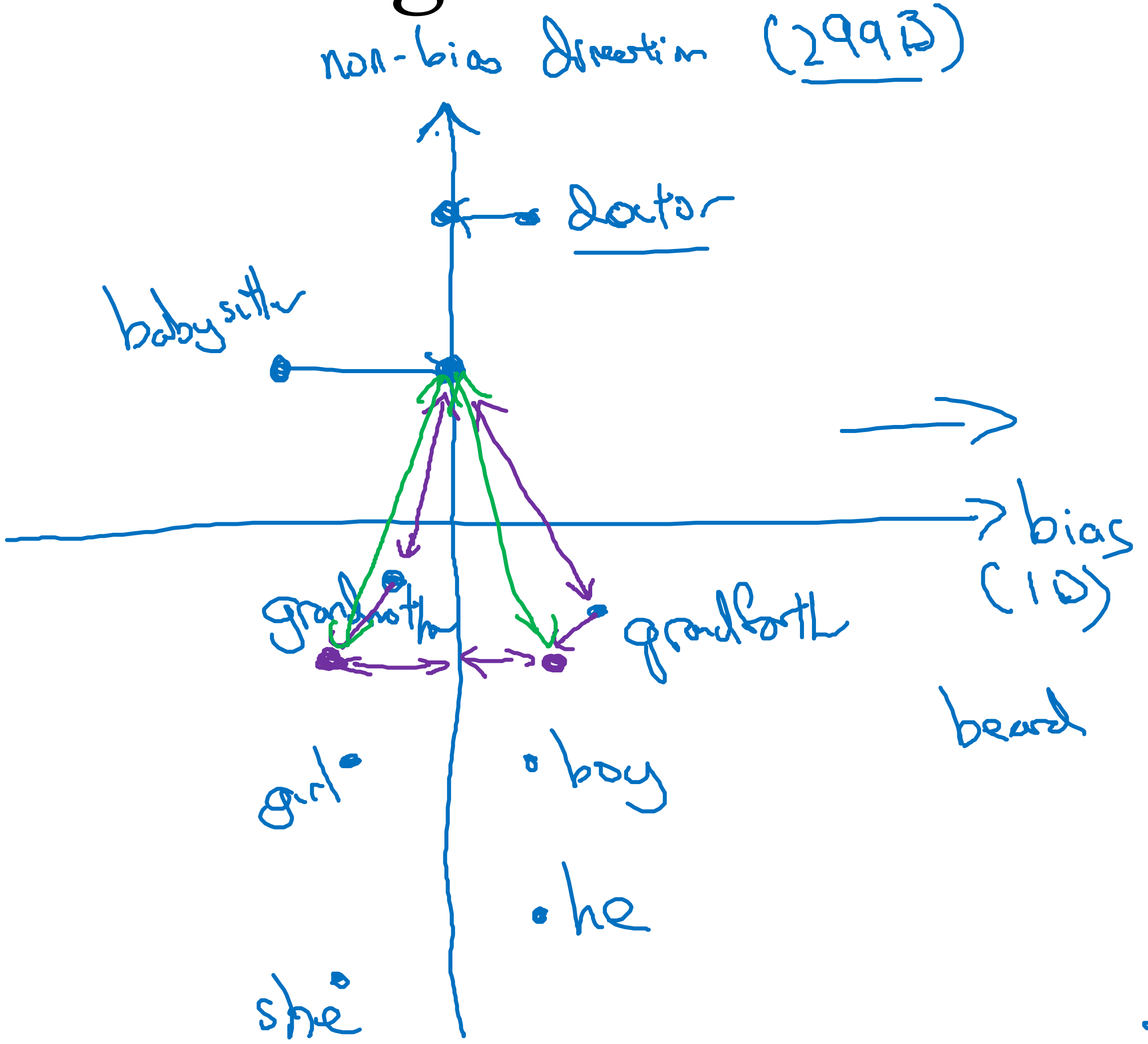
Addressing bias in word embeddings



1. Identify bias direction.

$e_{he} - e_{she}$

$e_{male} - e_{female}$

⋮

average

2. Neutralize: For every word that is not definitional, project to get rid of bias.

3. Equalize pairs.

→ grandmother – grandfather

girl – boy

[Bolukbasi et. al., 2016. Man is to computer programmer as woman is to homemaker? Debiasing word embeddings]