NATURAL LANGUAGE PROCESSING

MAIN INFORMATION SOURCES NOWADAYS

- language based
  - written text
  - speech
- visual
  - images ✓
  - video

SPEECH TO TEXT CONVERSION

- subtitles
- voice commands (hey Siri)
- 'writing' documents

TIMIT DATASET

- microphone speech
- phoneme level annotation
- English
- 630 speaker
- 1990s

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- microphone speech
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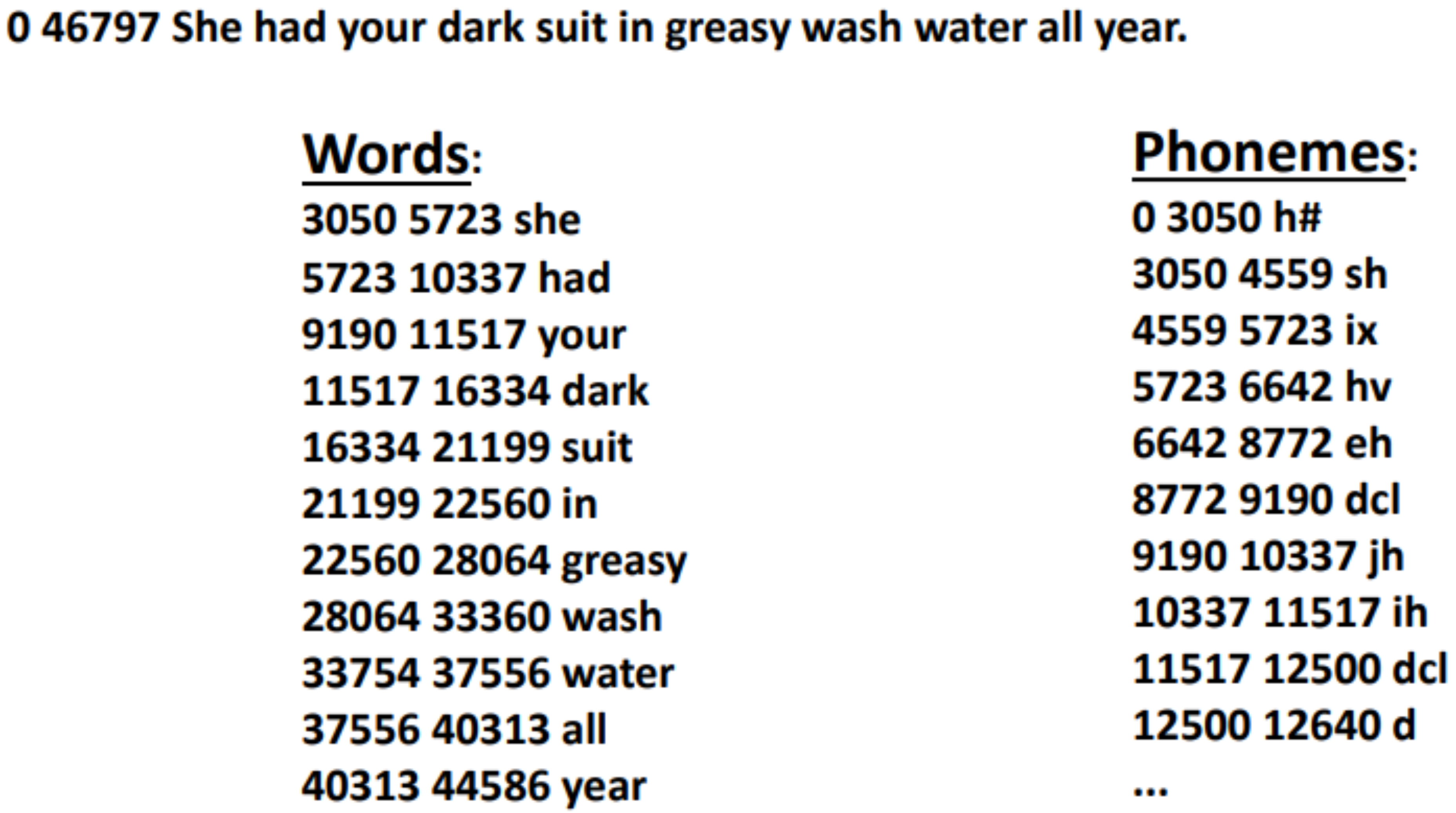


0 46797 She had your dark suit in greasy wash water all year.

Words:

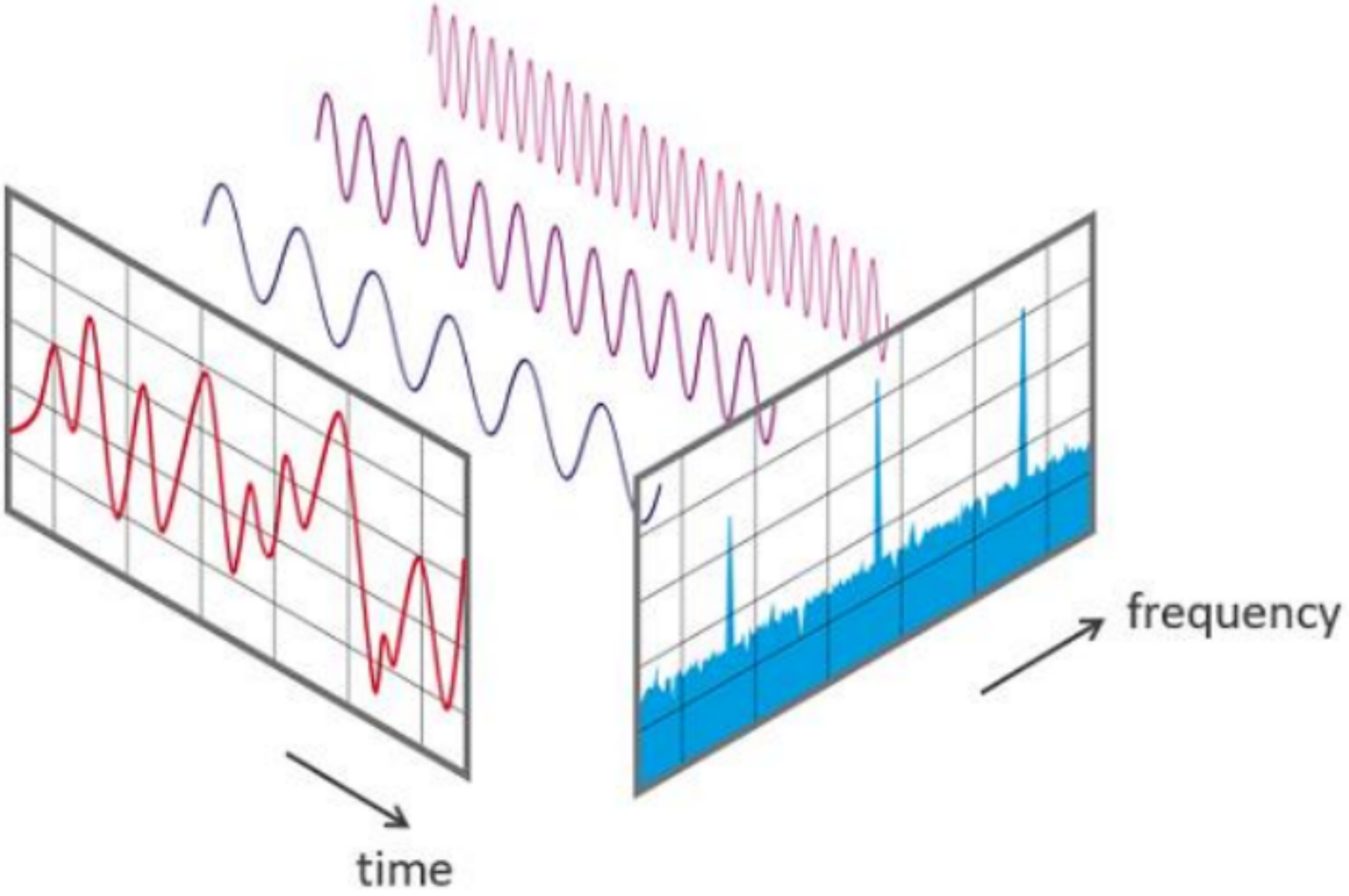
3050 5723 she
5723 10337 had
9190 11517 your
11517 16334 dark
16334 21199 suit
21199 22560 in
22560 28064 greasy
28064 33360 wash
33754 37556 water
37556 40313 all
40313 44586 year

Phonemes:

0 3050 h#
3050 4559 sh
4559 5723 ix
5723 6642 hv
6642 8772 eh
8772 9190 dcl
9190 10337 jh
10337 11517 ih
11517 12500 dcl
12500 12640 d
...

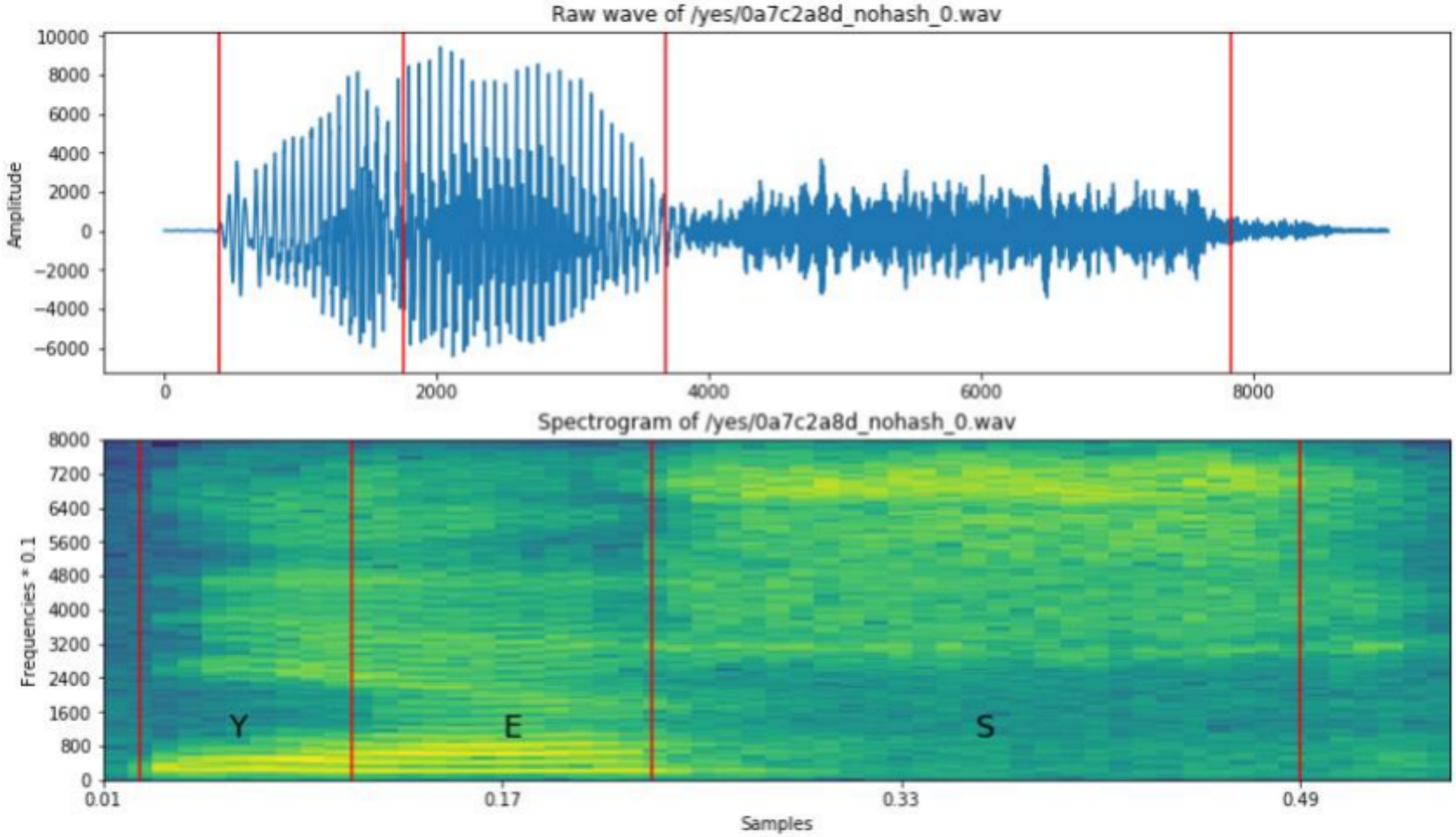
phoneme error rate

CONVERT SPEECH TO TEXT



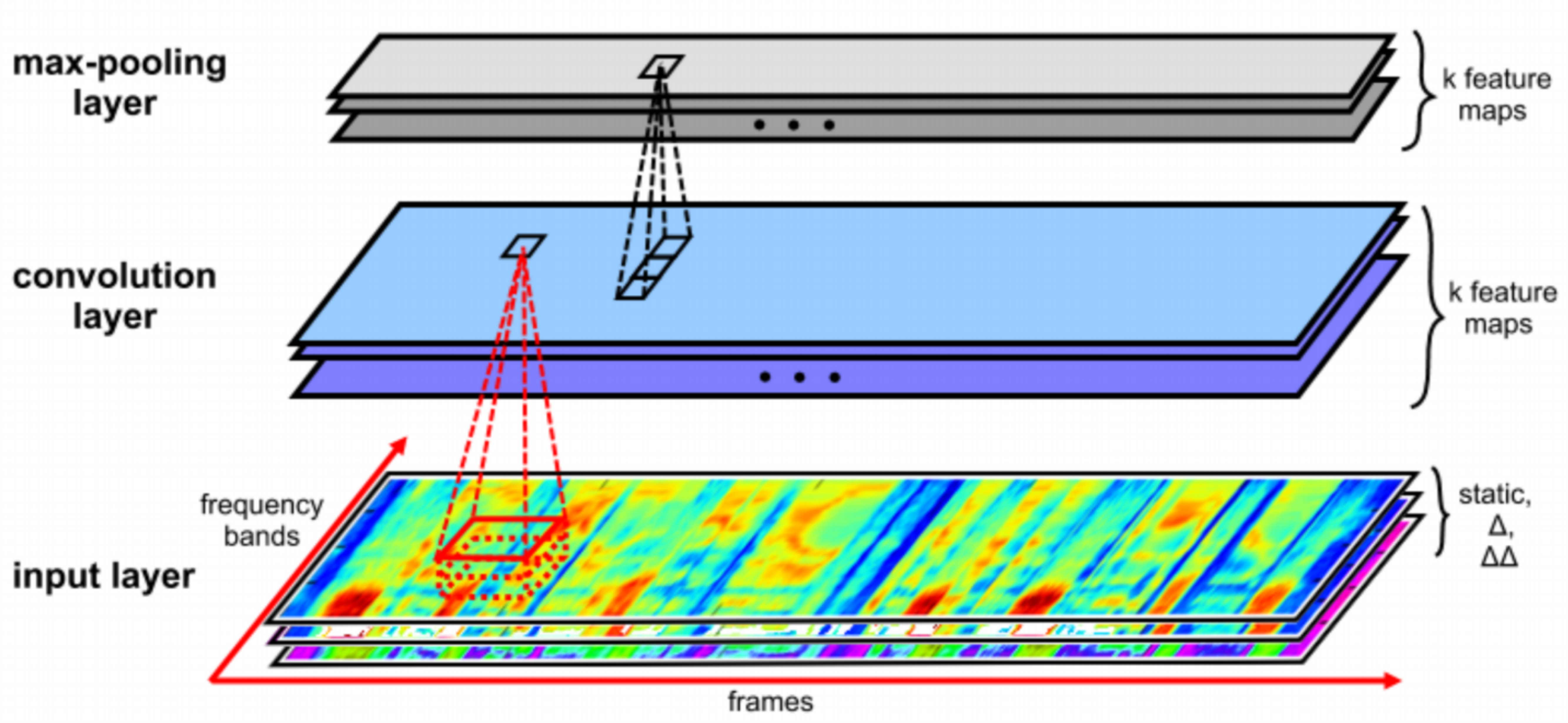
[By Phonical - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=64473578]

CONVERT SPEECH TO TEXT



[https://www.kaggle.com/davids1992/speech-representation-and-data-exploration]

CONVERT SPEECH TO TEXT



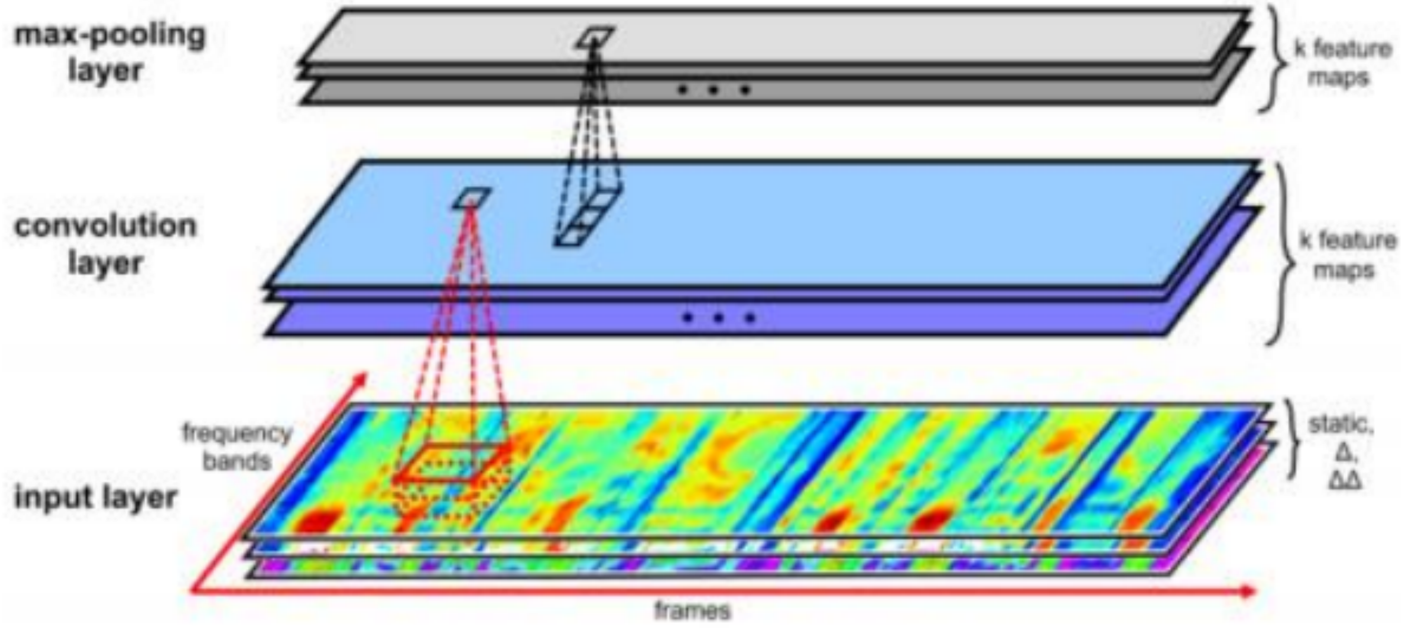
[Towards End-to-End Speech Recognition with Deep Convolutional Neural Networks,
Ying Zhang, Mohammad Pezeshki, Philemon Brakel, Saizheng Zhang, Cesar Laurent Yoshua Bengio, Aaron Courville, 2017]

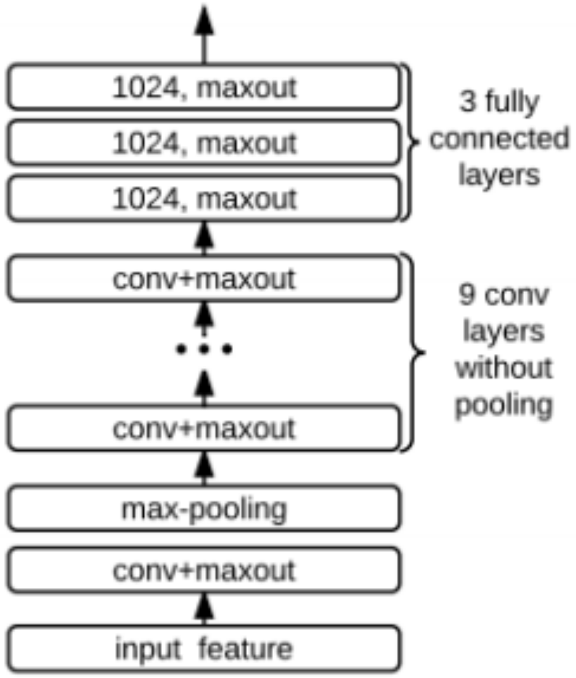
CONNECTIONIST TEMPORAL CLASSIFICATION

$$\left.\begin{array}{l} \sigma(a, b, c, -, -) \\ \sigma(a, b, -, c, c) \\ \sigma(a, a, b, b, c) \\ \sigma(-, a, -, b, c) \\ \quad\vdots \\ \sigma(-, -, a, b, c) \end{array}\right\} = (a, b, c).$$

[Towards End-to-End Speech Recognition with Deep Convolutional Neural Networks,
Ying Zhang, Mohammad Pezeshki, Philemon Brakel, Saizheng Zhang, Cesar Laurent Yoshua Bengio, Aaron Courville, 2017]

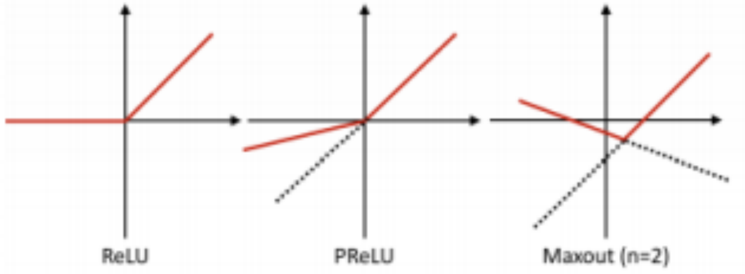
CONVERT SPEECH TO TEXT





$$\left.\begin{array}{l}\sigma(a,b,c,-,-)\\ \sigma(a,b,-,c,c)\\ \sigma(a,a,b,b,c)\\ \sigma(-,a,-,b,c)\\ \vdots\\ \sigma(-,-,a,b,c)\end{array}\right\} = (a,b,c).$$

Model	NP	Dev PER	Test PER
BiLSTM-3L-250H [12]	3.8M	-	18.6%
BiLSTM-5L-250H [12]	6.8M	-	18.4%
TRANS-3L-250H [12]	4.3M	-	18.3%
CNN-(3,5)-10L-ReLU	4.3M	17.4%	19.3%
CNN-(3,5)-10L-PReLU	4.3M	17.2%	18.9%
CNN-(3,5)-6L-maxout	4.3M	18.7%	21.2%
CNN-(3,5)-8L-maxout	4.3M	17.7%	19.8%
CNN-(3,3)-10L-maxout	4.3M	18.4%	19.9%
CNN-(3,5)-10L-maxout	4.3M	**16.7%**	**18.2%**



**[Towards End-to-End Speech Recognition with Deep Convolutional Neural Networks,
Ying Zhang, Mohammad Pezeshki, Philemon Brakel, Saizheng Zhang, Cesar Laurent Yoshua Bengio, Aaron Courville, 2017]**

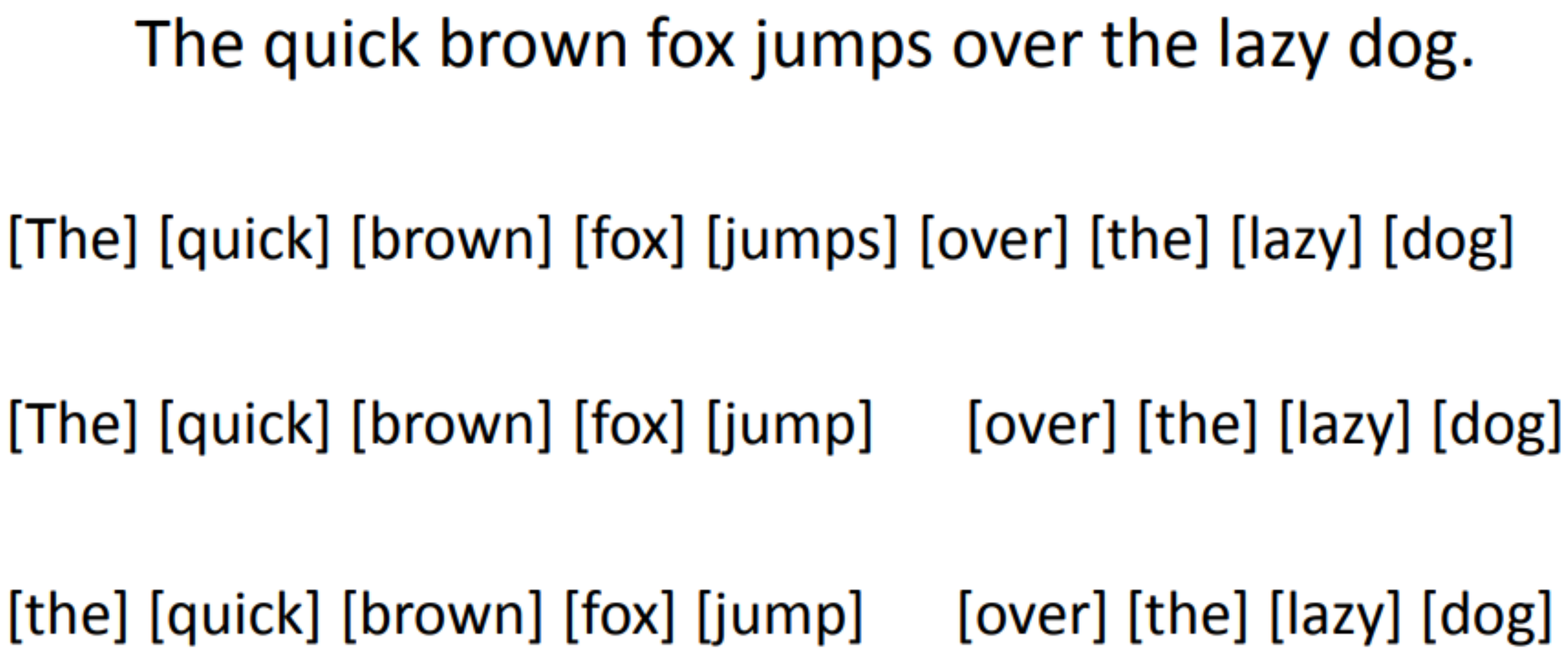
HANDLING TEXT

- **sentiment analysis**
- **next word prediction**
- **question answering**
- **language translation**
- **etc ...**

For each above the text should be represented in a computer friendly format.

REPRESENTING WORDS

- **corpus - the given text we use for ML**
- **tokenization - split of the text to words**
- **stemming - converting everything to singular & removing affixations (eq going -> go, dogs -> dog)**
- **vocabulary - unique set of the stemmed tokens**



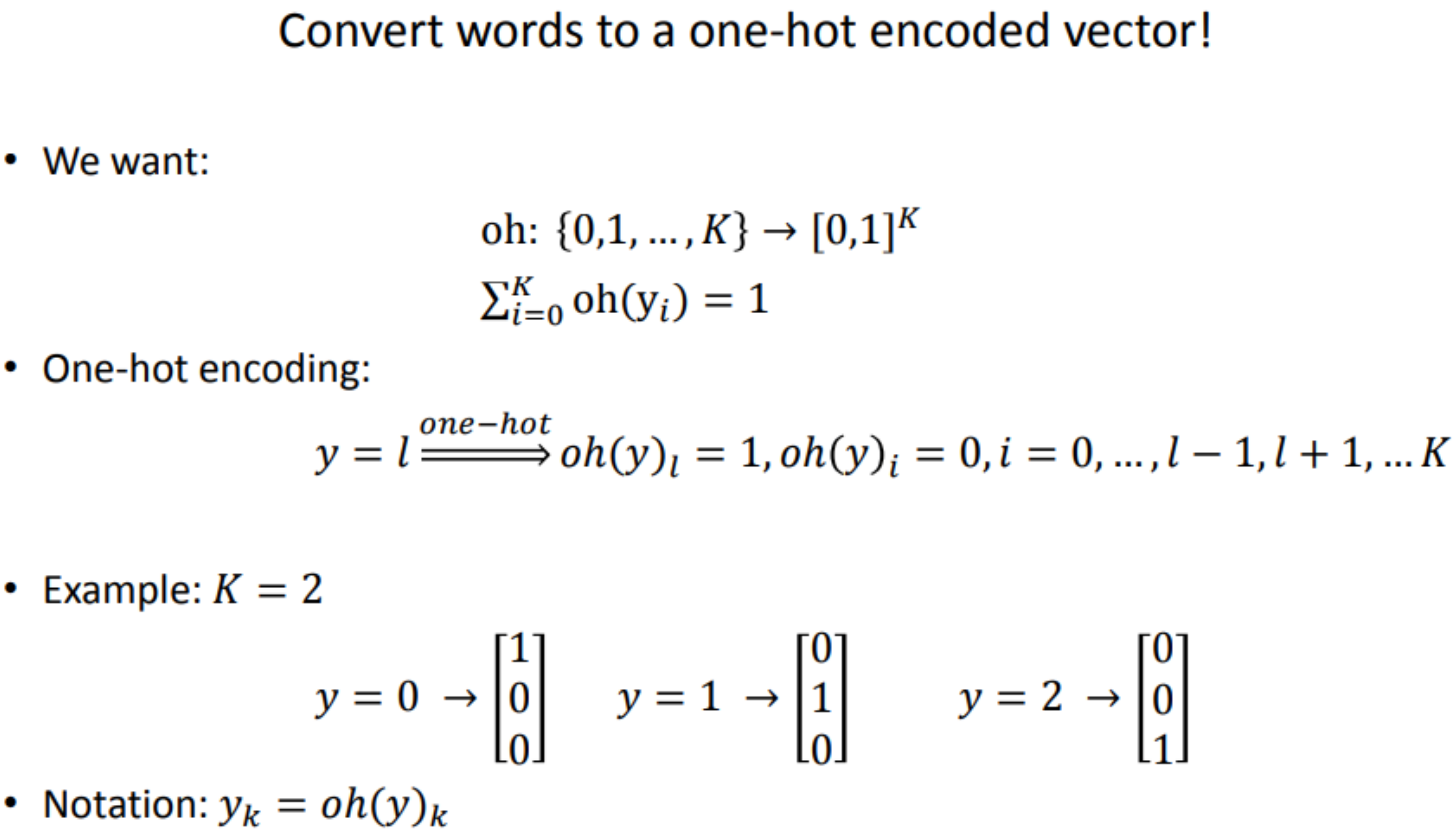
The quick brown fox jumps over the lazy dog.

[The] [quick] [brown] [fox] [jumps] [over] [the] [lazy] [dog]

[The] [quick] [brown] [fox] [jump]   [over] [the] [lazy] [dog]

[the] [quick] [brown] [fox] [jump]   [over] [the] [lazy] [dog]

REPRESENTING WORDS



Convert words to a one-hot encoded vector!

- We want:

$$\text{oh}: \{0,1,\dots,K\} \to [0,1]^K$$

$$\textstyle\sum_{i=0}^{K} \text{oh}(y_i) = 1$$

- One-hot encoding:

$$y = l \overset{one-hot}{\Longrightarrow} oh(y)_l = 1, oh(y)_i = 0, i = 0, \dots, l-1, l+1, \dots K$$

- Example: $K = 2$

$$y = 0 \to \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \quad y = 1 \to \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \quad y = 2 \to \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

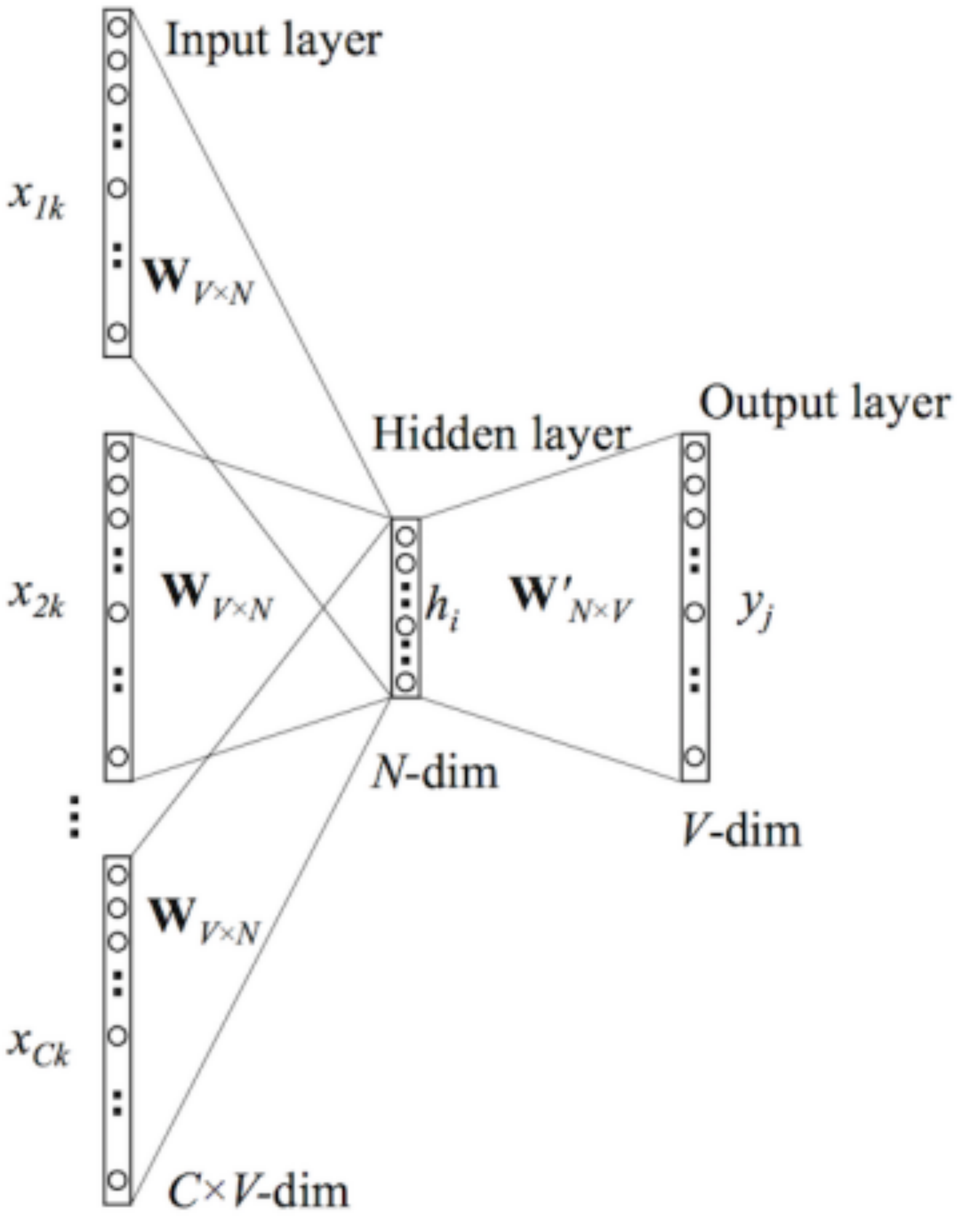
- Notation: $y_k = oh(y)_k$

Still we have too many words and we don't know the connection between them! (Each is orthogonal to the others)

Would be great to assign a D dimensional vector to each word where that vector represents the meaning of the word.

CONTINUOUS BAG OF WORDS (CBOW)

[the] [quick] [brown] [fox] [jump] [over] [the] [lazy] [dog]



N ~ O(100)

V ~ O(10000)

Mikolov et al, Efficient Estimation of Word Representations in Vector Space. 2013

CONTINUOUS BAG OF WORDS (CBOW)

[the] [quick] [brown] [fox] [jump] [over] [the] [lazy] [dog]

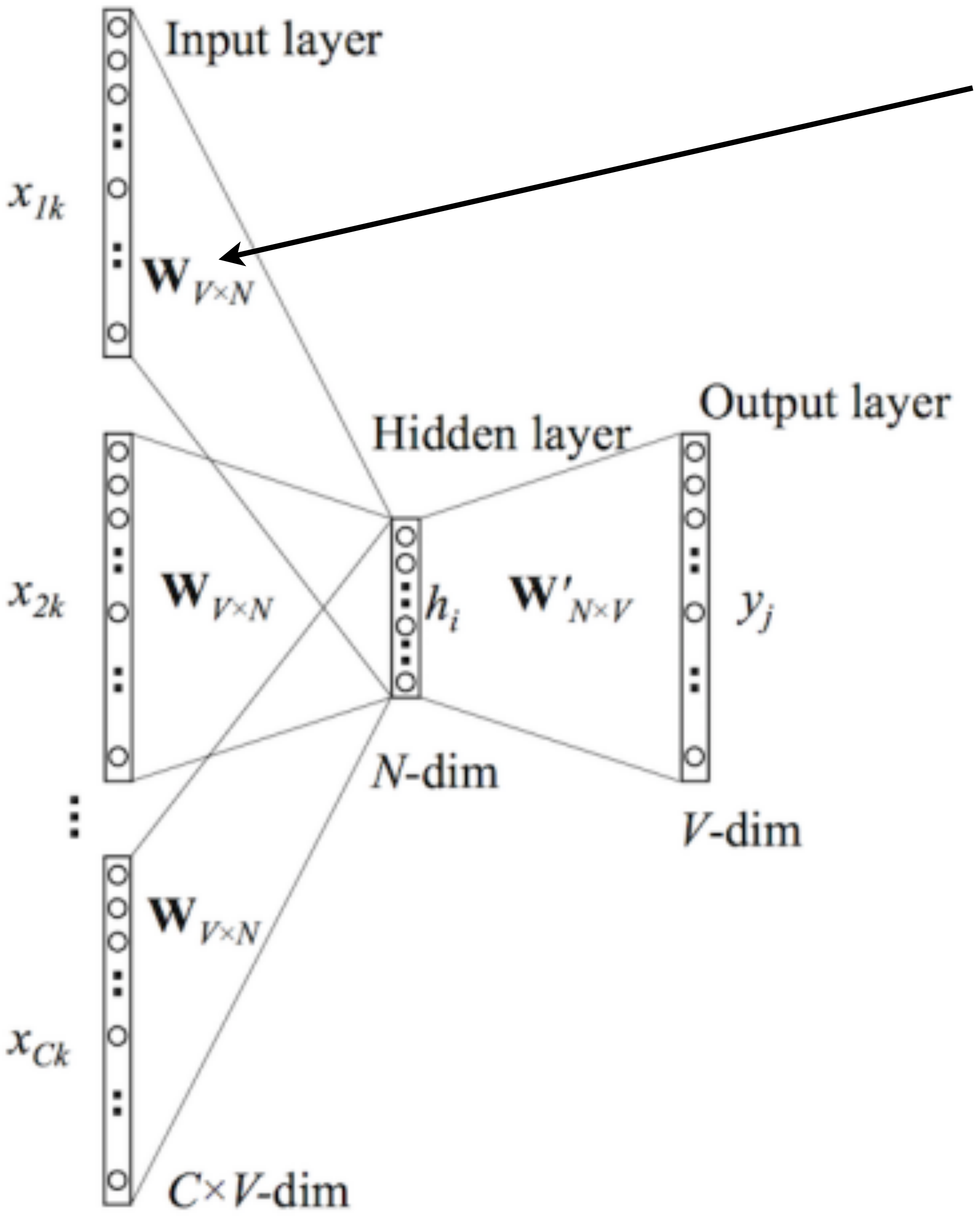
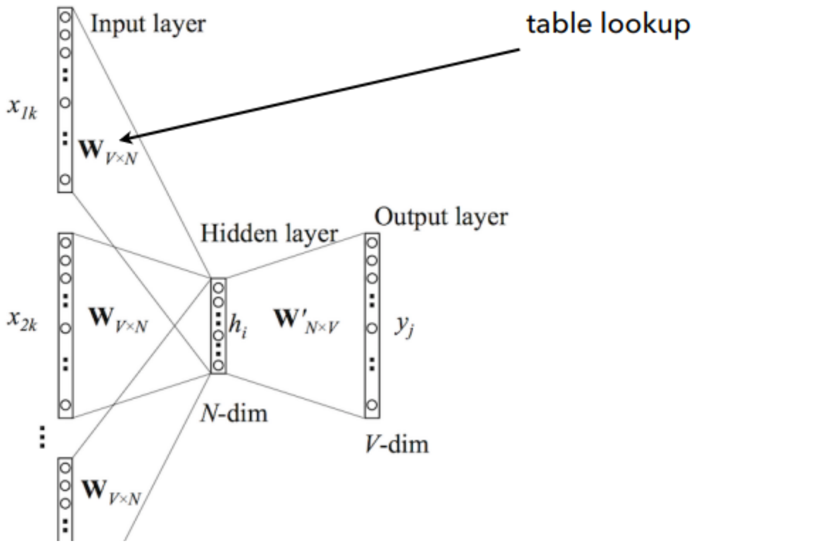


table lookup

Mikolov et al, Efficient Estimation of Word Representations in Vector Space. 2013

CONTINUOUS BAG OF WORDS (CBOW)

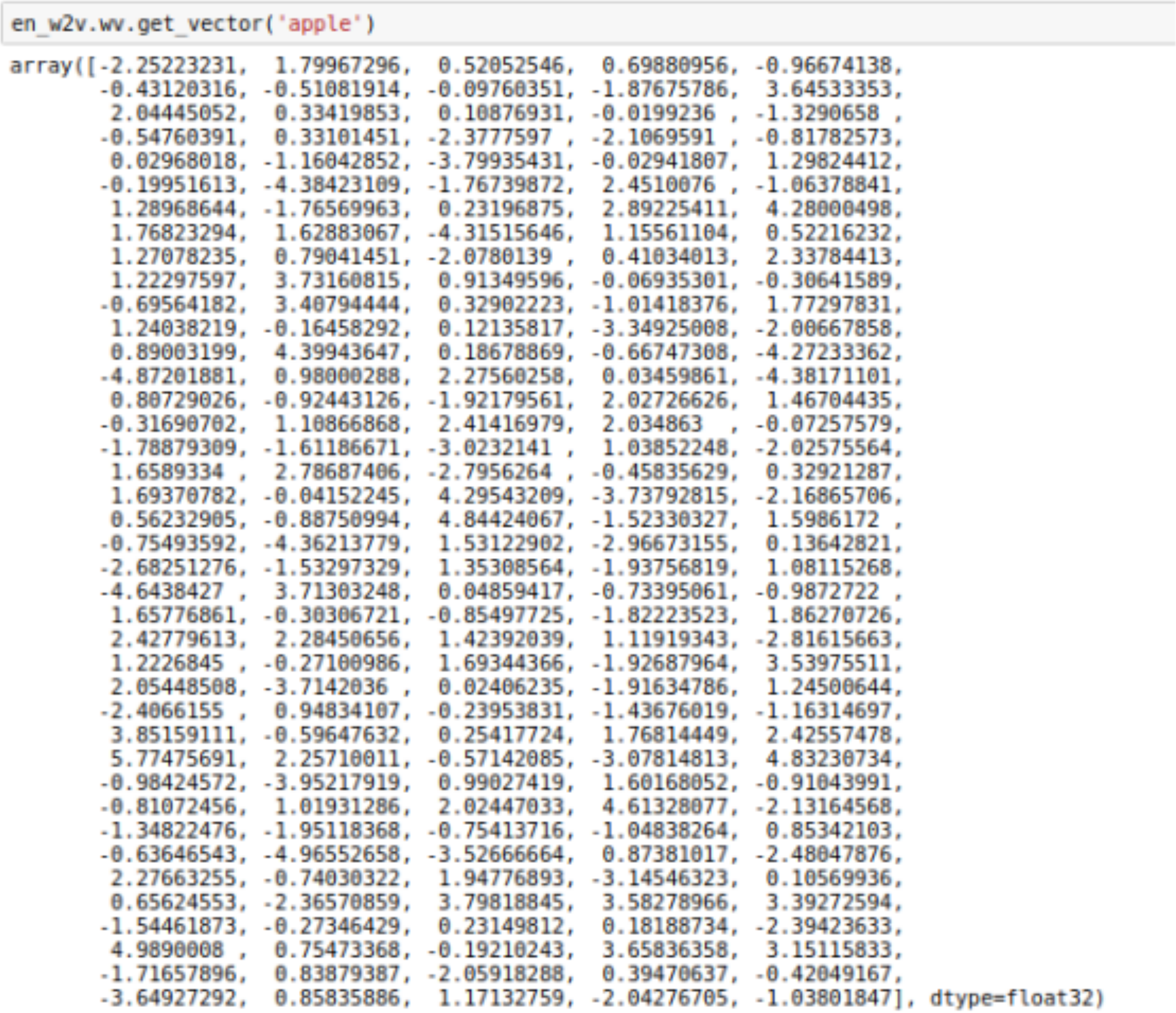
[the] [quick] [brown] [fox] [jump] [over] [the] [lazy] [dog]



ns in Vector Space. 2013

$$\begin{pmatrix} 0 & 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 30 & 45 & 12 & 87 & 72 \\ 2 & 42 & 88 & 23 & 24 \\ 98 & 100 & 42 & 60 & 20 \\ 68 & 100 & 66 & 60 & 84 \\ 70 & 68 & 64 & 63 & 87 \end{pmatrix}$$

MEANING OF WORDS



```
en_w2v.wv.get_vector('apple')
```

```
array([-2.25223231,  1.79967296,  0.52052546,  0.69880956, -0.96674138,
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        2.04445052,  0.33419853,  0.10876931, -0.0199236 , -1.3290658 ,
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```

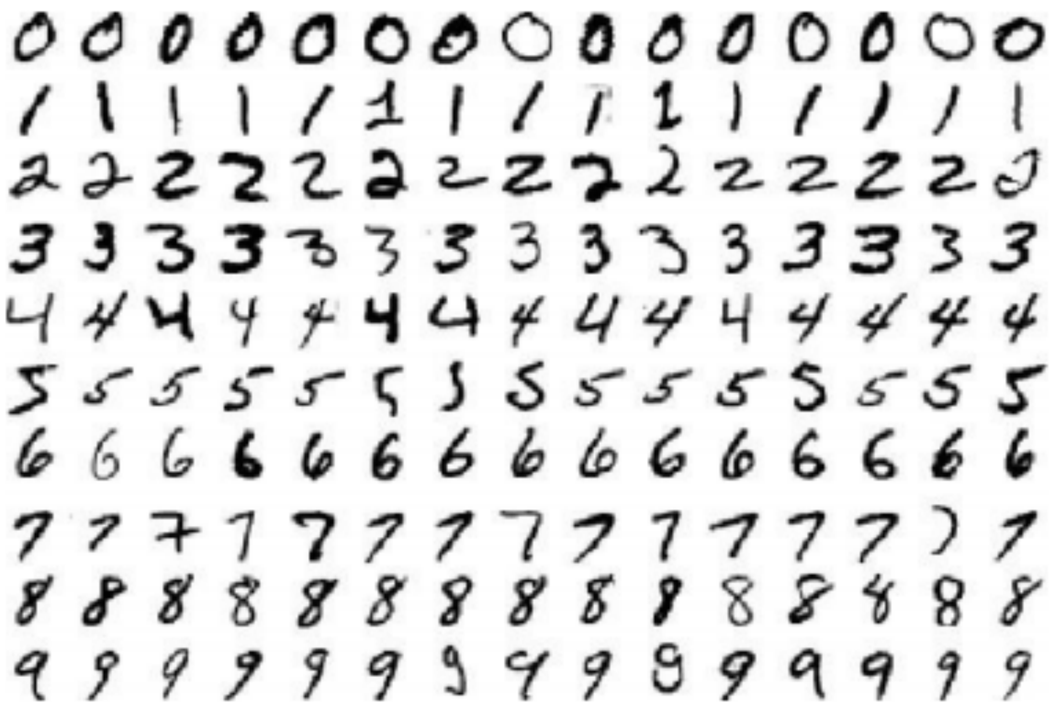
Vector representation:

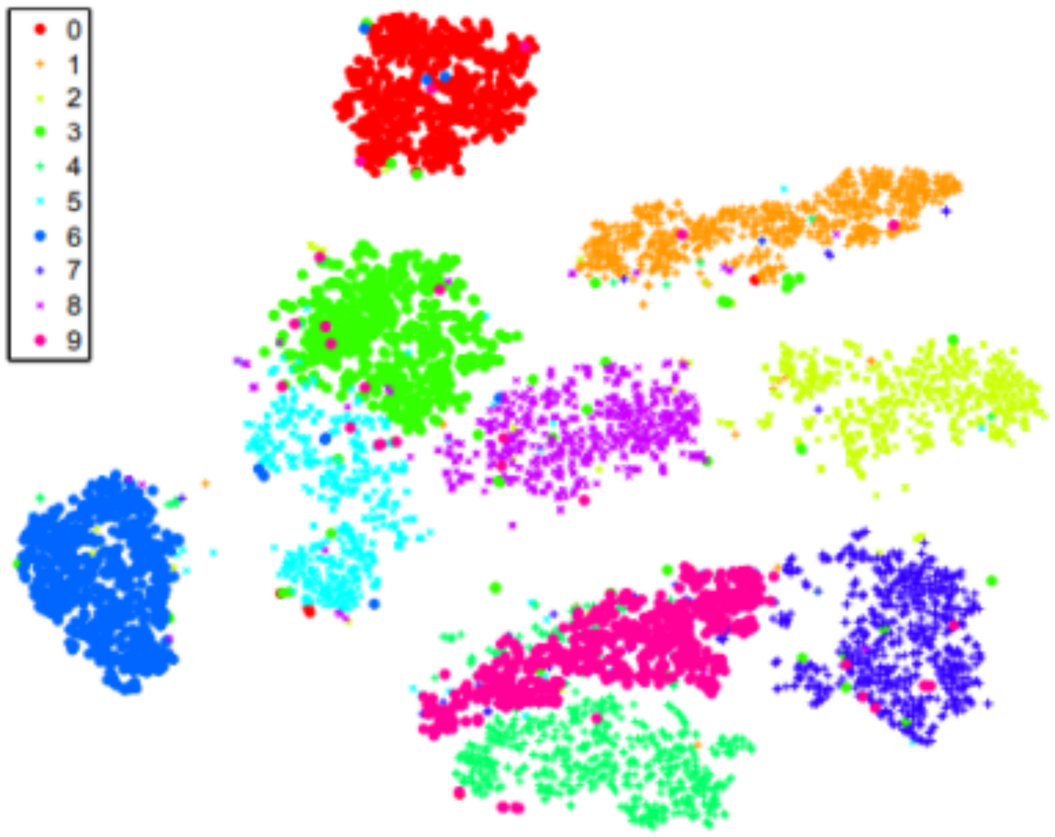
- cosine distance:

$$d(x, y) = \frac{xy}{\|x\| * \|y\|}$$

T-SNE - VISUALIZATION OF HIGH DIMENSIONAL DATA

VAN DER MAATEN AND HINTON





(a) Visualization by t-SNE.

[Visualizing Data using t-SNE *Laurens van der Maaten, Geoffrey Hinton*; 9(Nov):2579--2605, 2008.]

T-SNE – VISUALIZATION OF HIGH DIMENSIONAL DATA

$$p_{j|i} = \frac{\exp(-\|\mathbf{x}_i - \mathbf{x}_j\|^2 / 2\sigma_i^2)}{\sum_{k \neq i} \exp(-\|\mathbf{x}_i - \mathbf{x}_k\|^2 / 2\sigma_i^2)}, \qquad p_{ij} = \frac{p_{j|i} + p_{i|j}}{2N}$$

$$q_{ij} = \frac{(1 + \|\mathbf{y}_i - \mathbf{y}_j\|^2)^{-1}}{\sum_{k \neq i} (1 + \|\mathbf{y}_i - \mathbf{y}_k\|^2)^{-1}}$$

Minimize the Kullback-Leibler divergence:

$$KL(P||Q) = \sum_{i \neq j} p_{ij} \log \frac{p_{ij}}{q_{ij}}$$

DEMO NOTEBOOKS

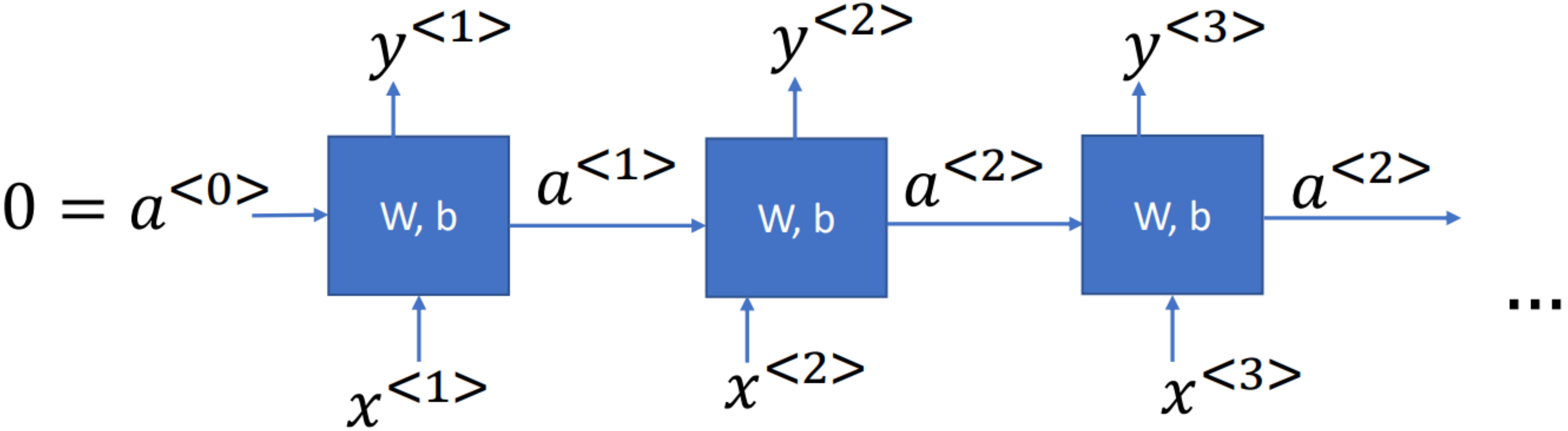
training a word2vec on Wikipedia

exploring the word2vec's word embeddings

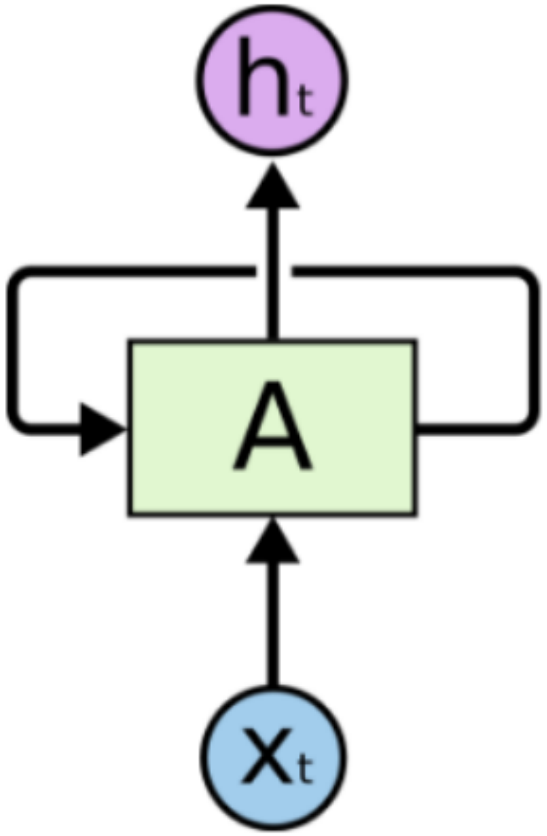
SEQUENCE TO SEQUENCE MODELS

- Speech recognition
  - Input: sequence of pressure values
  - Output: sequence of words
- Music generation
  - Input: 0
  - Output sequence of notes
- Sentiment classification
  - Input: sequence of words
  - Output: rating (1-5)
- Machine translation
  - Input: sequence of words
  - Output: sequence of words
- Video activity recognition, summarization, etc.:
  - Input: sequence of pictures
  - Output: labels, sequence of words, etc.

RECURRENT NEURAL NETWORK (RNN)



- $a^{<1>} = g(W_{aa}a^{<0>} + W_{ax}x^{<1>} + b_a)$
- $y^{<1>} = g\left(W_{ya}a^{<1>} + b_y\right)$
- $a^{<2>} = g(W_{aa}a^{<1>} + W_{ax}x^{<2>} + b_a)$
- $y^{<2>} = g\left(W_{ya}a^{<2>} + b_y\right)$
- ...



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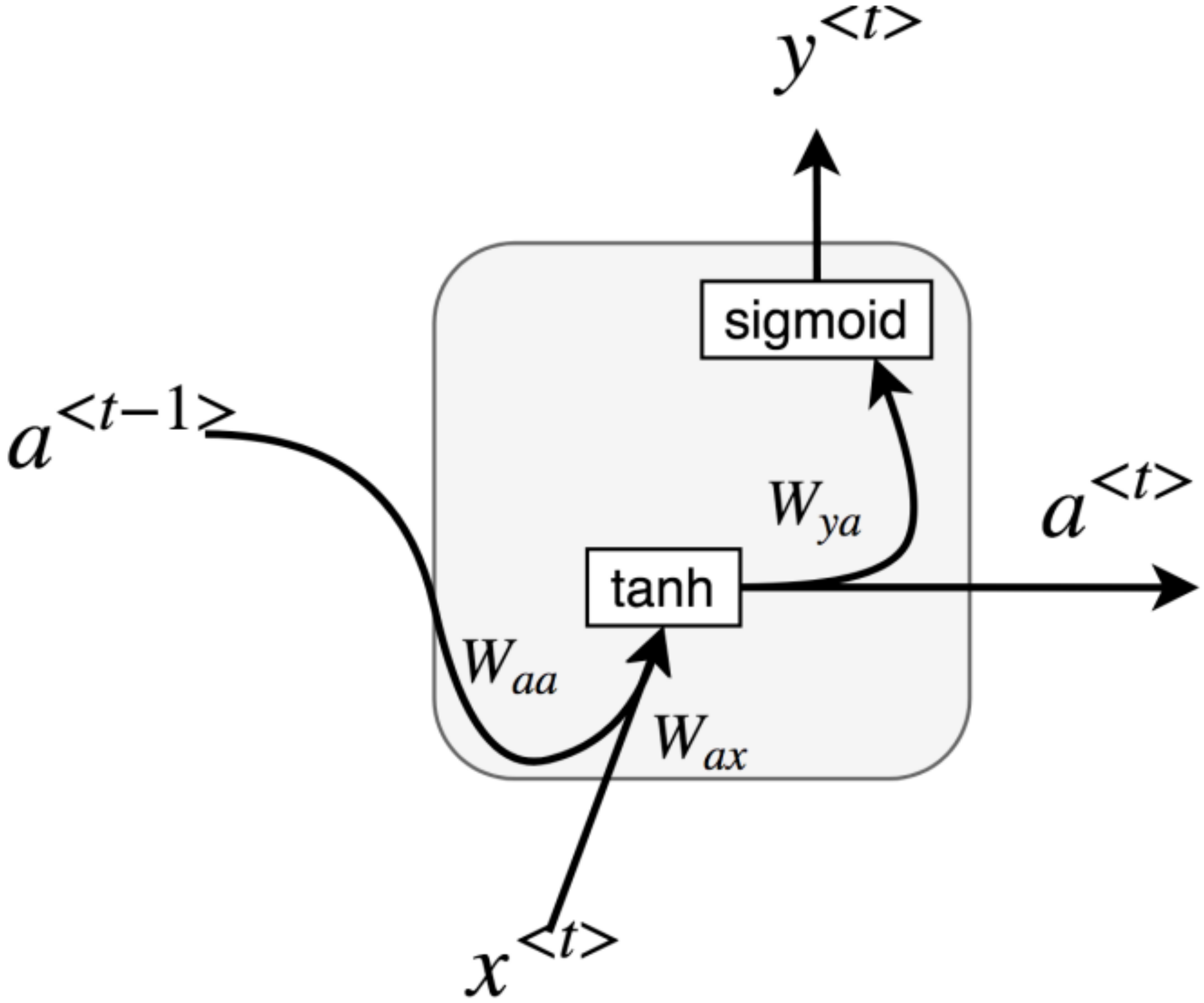
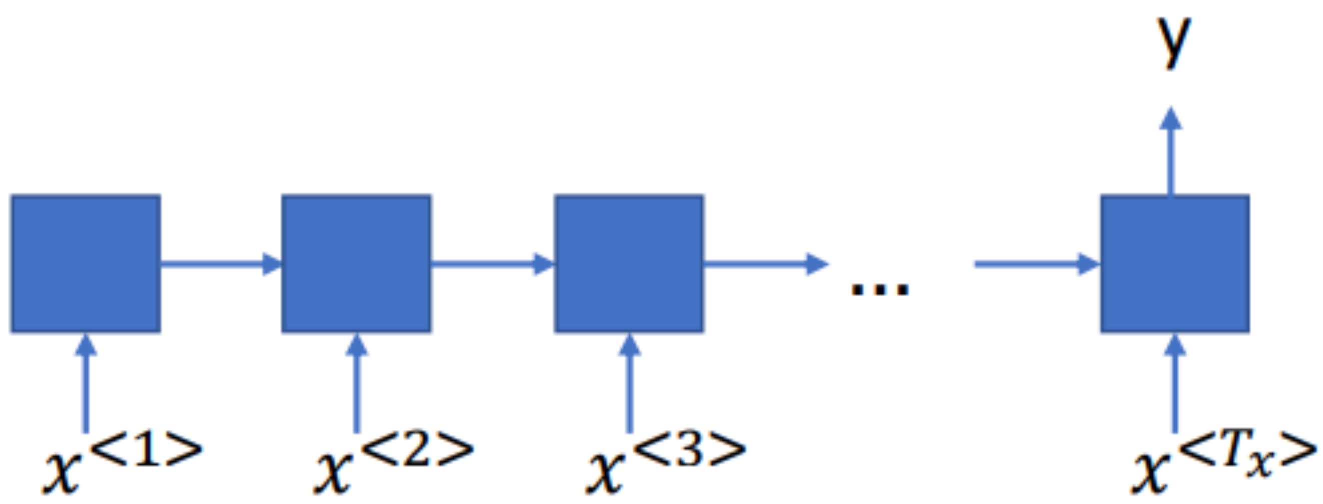
RNN CELL

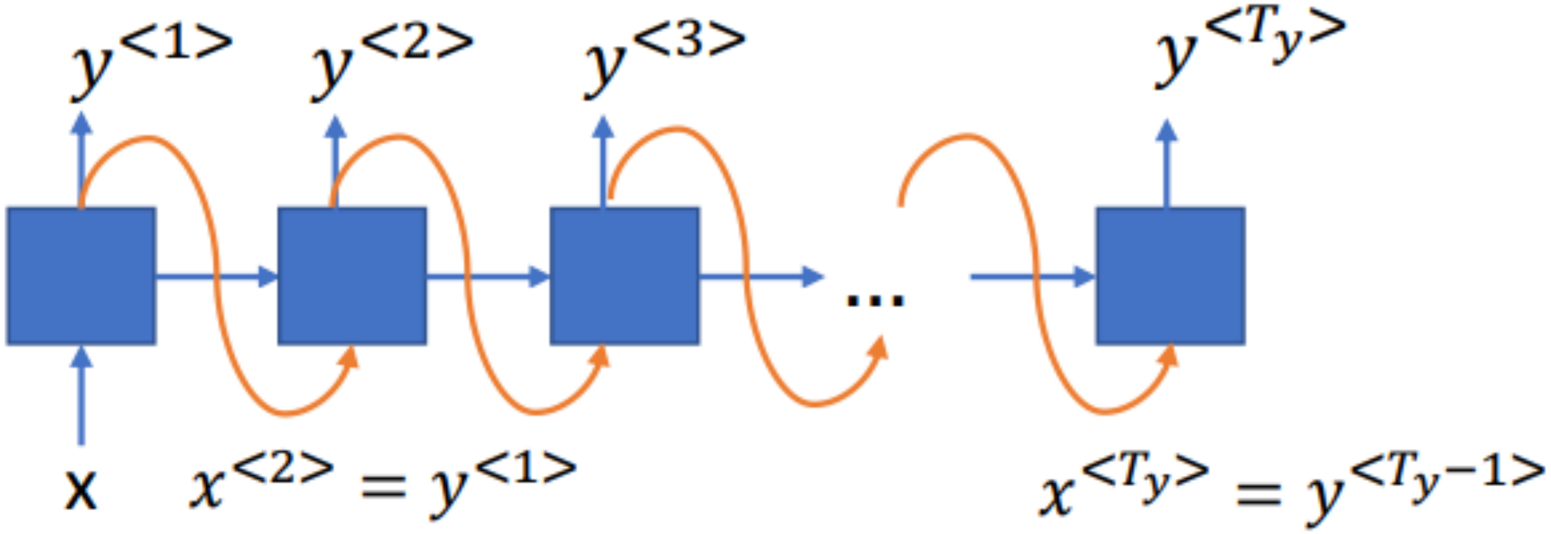


RNN ARCHITECTURES

- Many-to-one (e.g. sentiment classification)

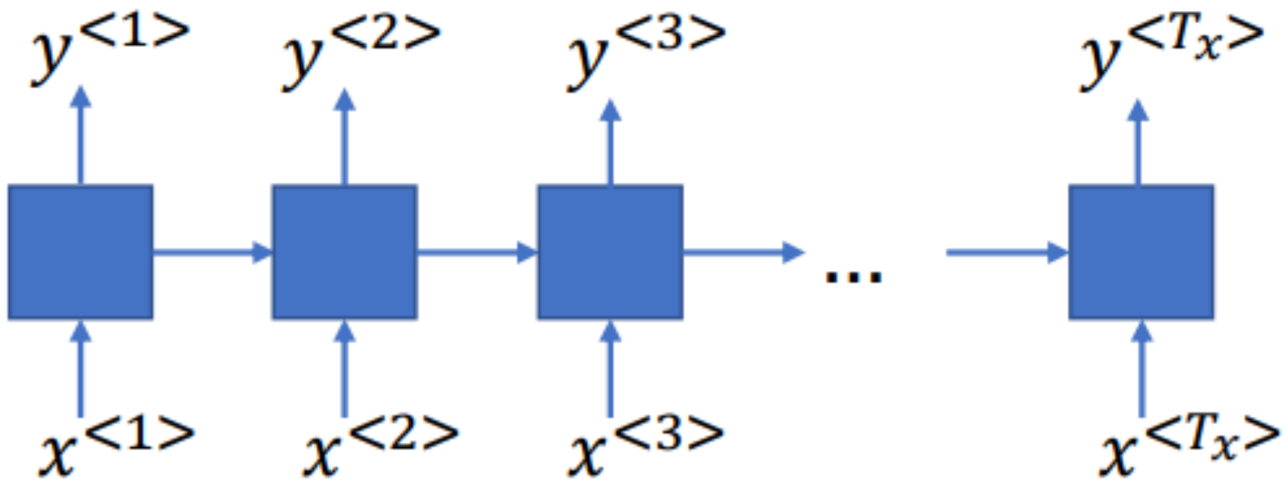


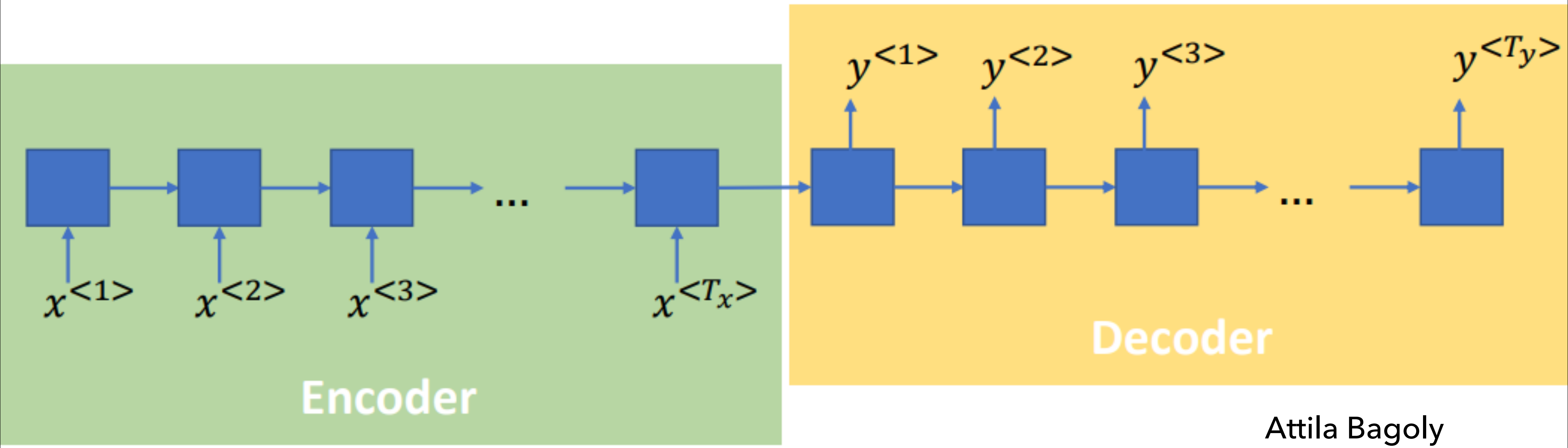
- One-to-many (e.g. music generation)



RNN ARCHITECTURES

- Many-to-many: 2 case: $T_x = T_y$ or $T_x \neq T_y$





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Detailed RNN comes later…