# Natural Language Processing: Classification

HSE Faculty of Computer Science

Machine Learning and Data-Intensive Systems

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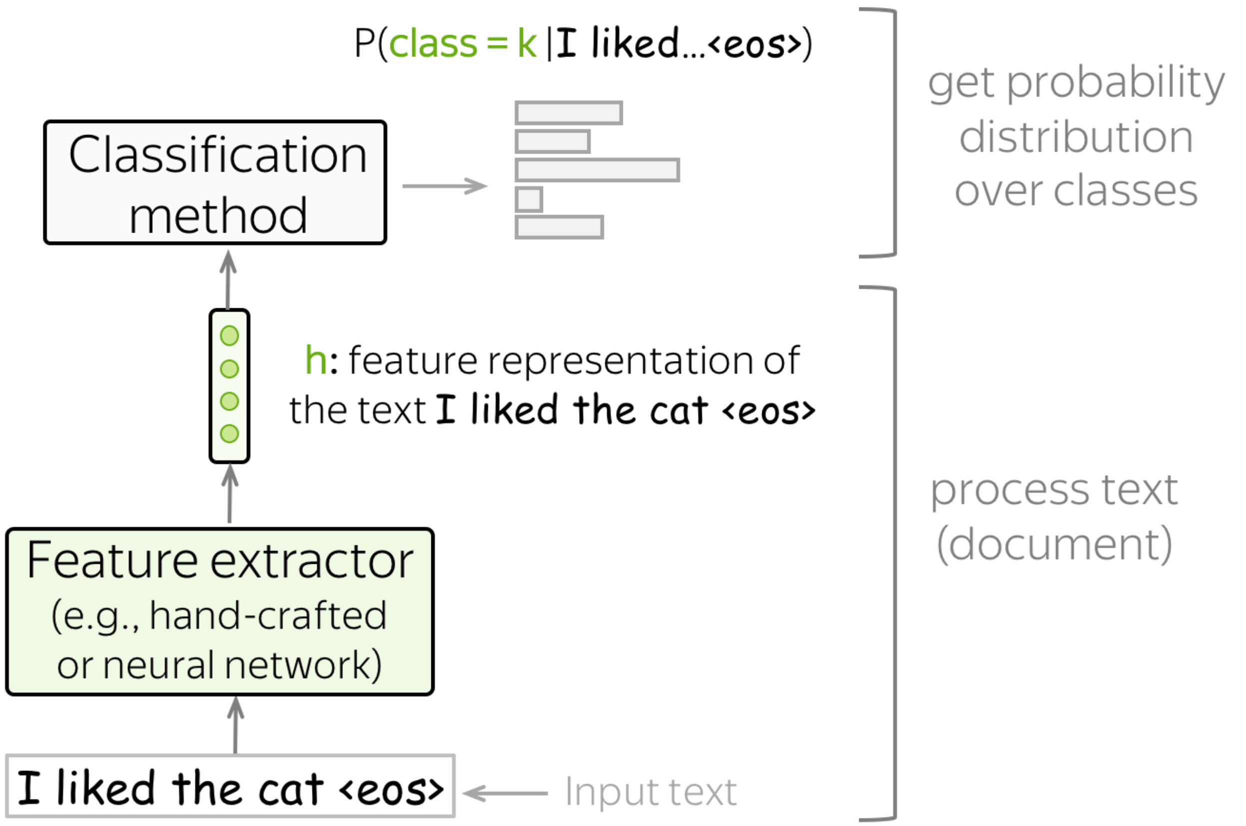
# Extract features, apply model, compare the distribution to the target




Source: https://lena-voita.github.io/nlp_course/text_classification.html

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# Naively count the conditional probability

Bayes' rule
(hence Naïve Bayes)

Ignore P(x) – it does not
influence the argmax

$$y^* = \arg\max_k P(y=k|x) = \arg\max_k \frac{P(x|y=k)\cdot P(y=k)}{P(x)} = \arg\max_k \underbrace{P(x|y=k)}_{} \cdot \underbrace{P(y=k)}_{}$$

need to define this

Source: https://lena-voita.github.io/nlp_course/text_classification.html

# Naively count the conditional probability

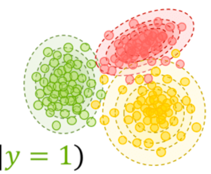
The Naive Bayes assumptions are

•Bag of Words assumption: word order does not matter

•Conditional Independence assumption: features (words) are independent given the class

$$y^* = \arg\max_k \underbrace{P(y = k|x)} = \arg\max_k \underbrace{P(x|y = k)} \cdot \underbrace{P(y = k)} = \arg\max_k \underbrace{P(x, y = k)}$$

posterior probability: after looking at data (i.e., we know **x**)




prior probability: before looking at data (i.e., we don't know **x**)

joint probability (hence the model is **generative**)

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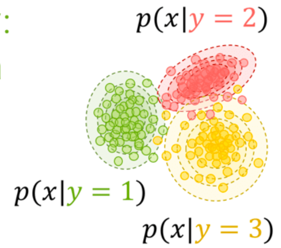
# How to define P(x|y=k) and P(y=k)

$$y^* = \arg\max_k \underbrace{P(y=k|x)}_{\substack{\text{posterior probability:}\\ \text{after looking at data}\\ \text{(i.e., we know } \mathbf{x}\text{)}}} = \arg\max_k \underbrace{P(x|y=k)} \cdot \underbrace{P(y=k)}_{\substack{\text{prior probability:}\\ \text{before looking at data}\\ \text{(i.e., we don't know } \mathbf{x}\text{)}}} = \arg\max_k \underbrace{P(x, y=k)}_{\substack{\text{joint probability}\\ \text{(hence the model}\\ \text{is } \textbf{generative}\text{)}}}$$




$$P(y=k) = \frac{N(y=k)}{\sum_i N(y=i)}$$

$$P(x|y=k) = P(x_1, \dots, x_n|y=k) = \prod_{t=1}^{n} P(x_t|y=k)$$

$$P(x_i|y=k) = \frac{N(x_i, y=k)}{\sum_{t=1}^{|V|} N(x_t, y=k)}$$

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# How to define P(x | y=k) and P(y=k)?

The Naive Bayes assumptions are

•Bag of Words assumption: word order does not matter,

•Conditional Independence assumption: features (words) are independent given the class.

$$P(y=k) = \frac{N(y=k)}{\sum_i N(y=i)}$$

$$P(x|y=k) = P(x_1, \dots, x_n|y=k) = \prod_{t=1}^{n} P(x_t|y=k)$$

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## What if $N(x_i, y = k) = 0$? Need to avoid this!

nulls out token prob. $\Longrightarrow$ nulls out document probability $\Longrightarrow$ Bad!

$$N(x_i, y = k) \Longrightarrow P(x_i|y = k) = \frac{N(x_i, y = k)}{\sum_{t=1}^{|V|} N(x_t, y = k)} = 0 \Longrightarrow P(x|y = k) = \prod_{i=1}^{n} P(x_i|y = k) = 0$$

In training data, haven't seen token $x_i$ in documents of class $k$

$$P(x_i|y = k) = \frac{\delta + N(x_i, y = k)}{\sum_{t=1}^{|V|} (\delta + N(x_t, y = k))} = \frac{\delta + N(x_i, y = k)}{\delta \cdot |V| + \sum_{t=1}^{|V|} N(x_t, y = k)}$$

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# Making a prediction

Data: $x =$ This film is awesome !
($x_1$ = This, $x_2$ = film, $x_3$ = is, $x_4$ = awesome, $x_5$ = !)

Compute joint probability of data and class

**Positive class**

$$P(x, y=+) = P(y=+)\cdot P(x|y=+) = P(y=+)\cdot P(\text{This}|y=+)\cdot P(\text{film}|y=+)\cdot P(\text{is}|y=+)\cdot \boxed{P(\text{awesome}\,|y=+)}\cdot P(!|y=+)$$

**Negative class**

$$P(x, y=-) = P(y=-)\cdot P(x|y=-) = P(y=-)\cdot P(\text{This}|y=-)\cdot P(\text{film}|y=-)\cdot P(\text{is}\,|y=-)\cdot \boxed{P(\text{awesome}\,|y=-)}\cdot P(!\,|y=-)$$

Prior class probability (often 0.5)

Neutral words – not much difference in probabilities for classes

This is where we expect the difference:

$$P(\text{awesome}\,|y=+) \gg P(\text{awesome}|y=-)$$

$$P(x, y=+) > P(x, y=-) \Rightarrow y = +$$

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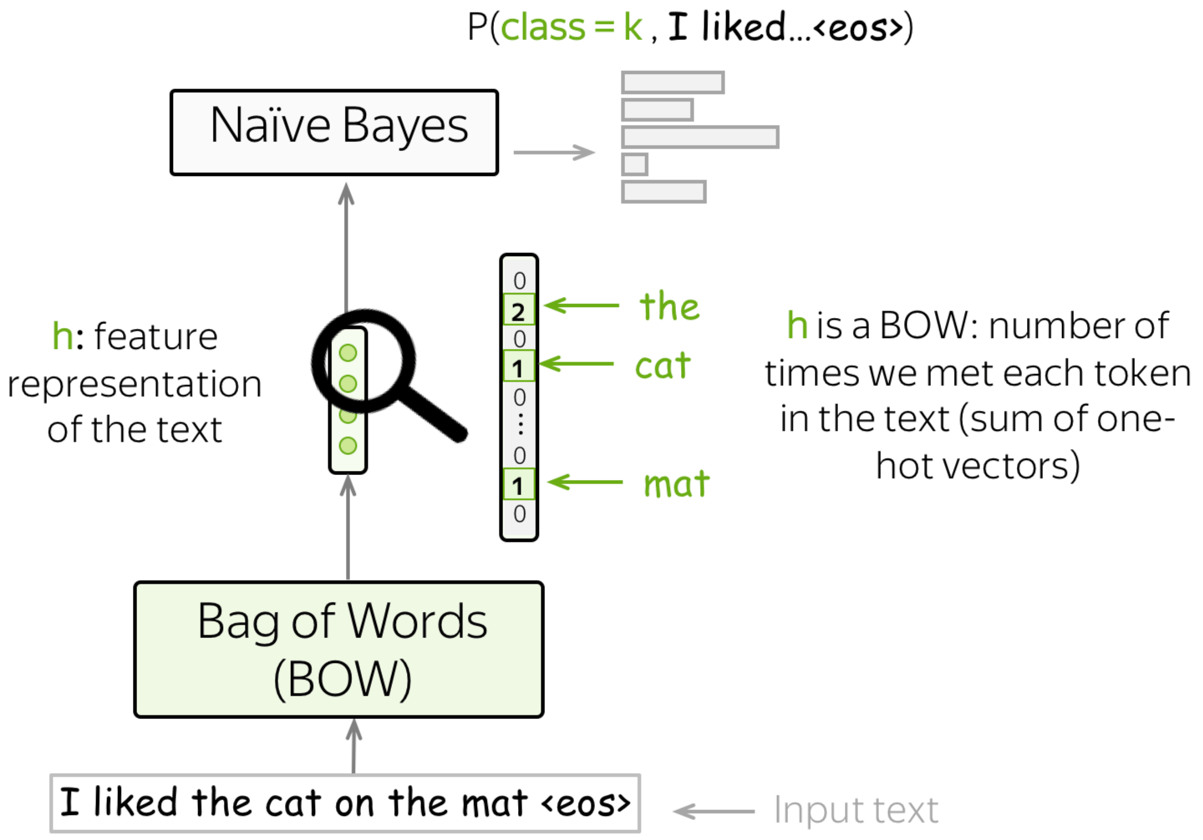
# View in the general framework

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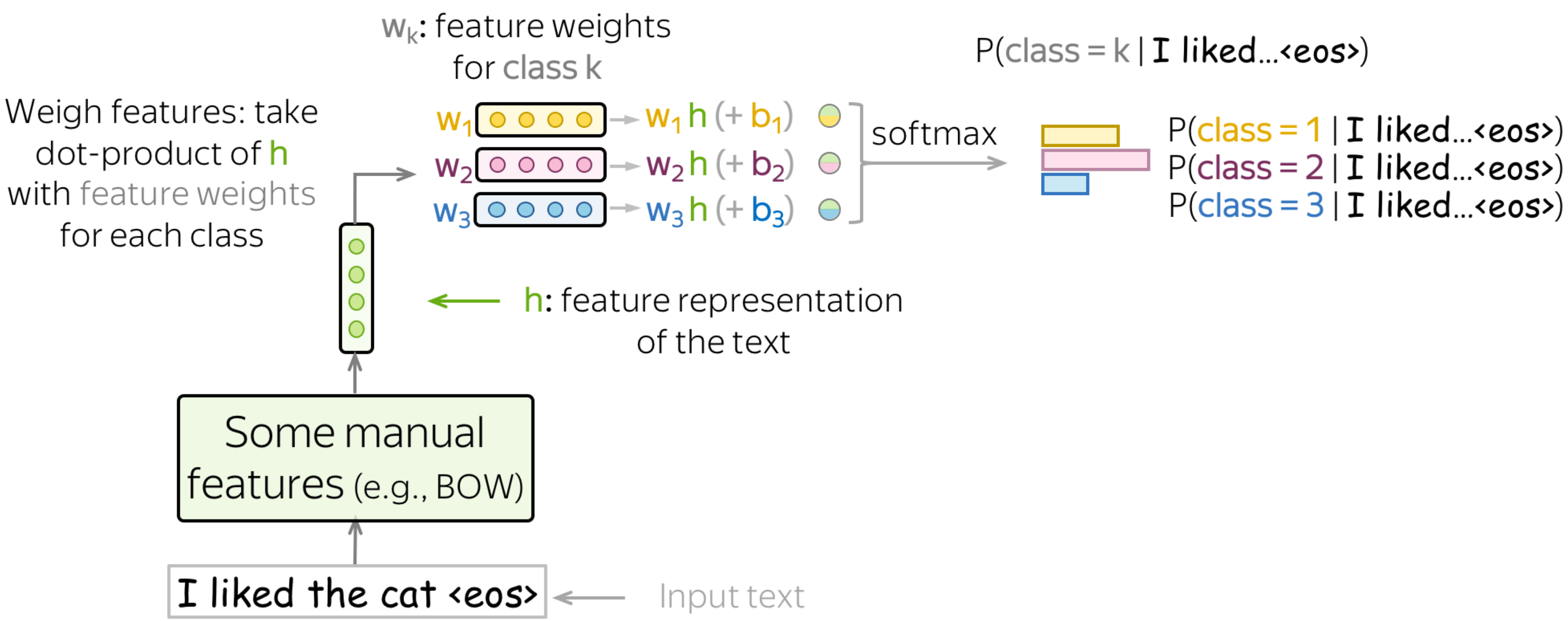
- General view on classification with text
- **Pre-deep learning approaches: Logistic Regression**
- Deep learning approaches
- Practical Tips

# Train a logistic regression

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# Loss function: log-loss

Given training examples $x^1, \dots, x^N$ with labels $y^1, \dots, y^N$, $y^i \in \{1, \dots, K\}$, we pick those weights $w^{(k)}, k = 1..K$ which maximize the probability of the training data:

$$w^* = \arg\max_w \sum_{i=1}^{N} \log P(y = y^i | x^i).$$

Source: https://lena-voita.github.io/nlp_course/text_classification.html

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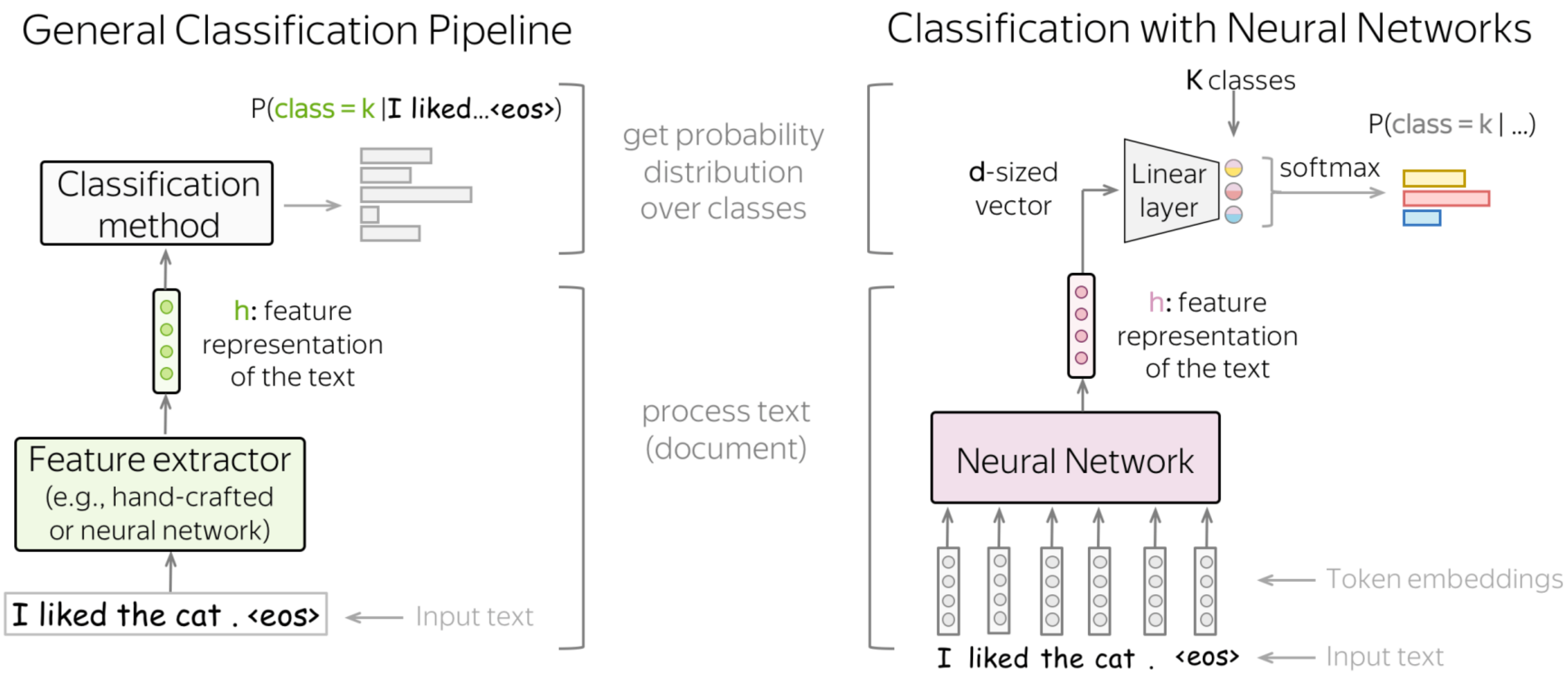
- Pre-deep learning approaches
- **Deep learning approaches: Overview**
- Practical Tips

# Overview of DL-based approaches

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# Overview of DL-based approaches

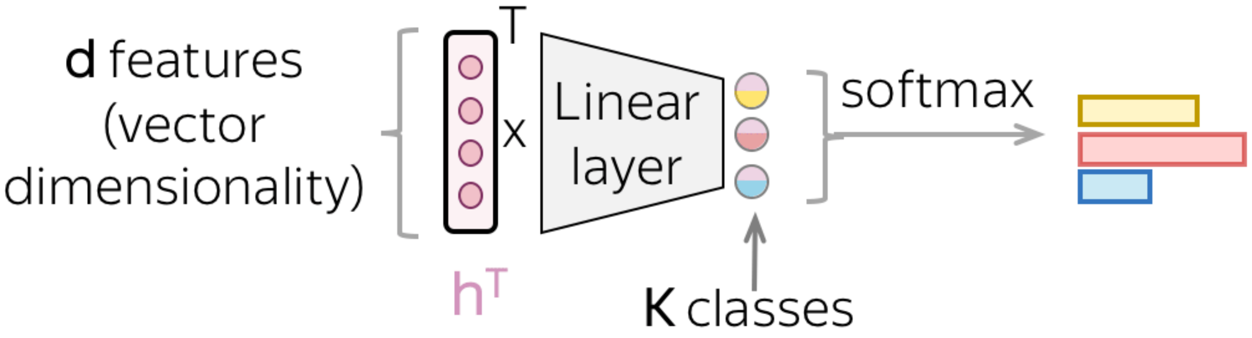
We have:

- $h$ - vector of size **d**

We need:

- vector of size **K** – probabilities for K classes

→ Transform linearly from size **d** to size **K**

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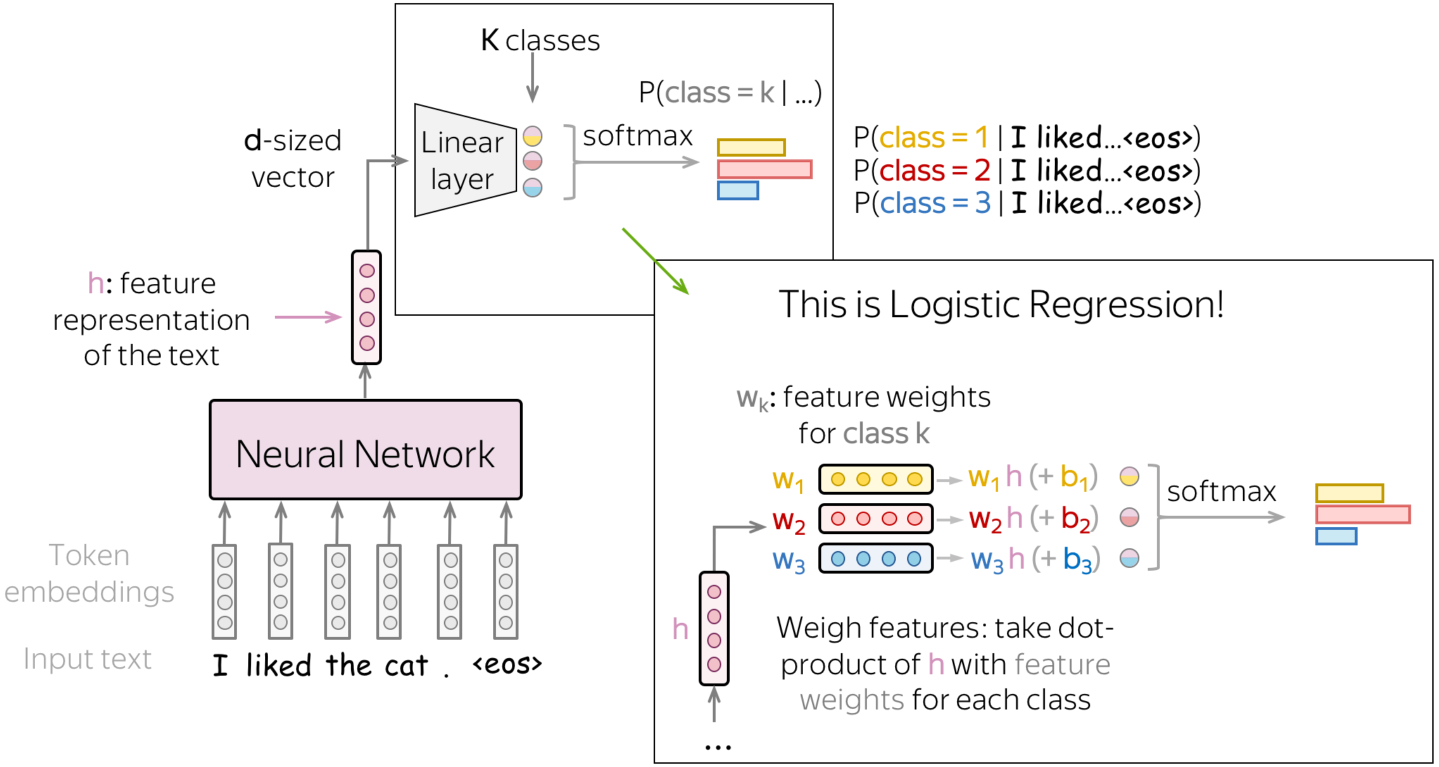
# Overview of DL-based approaches

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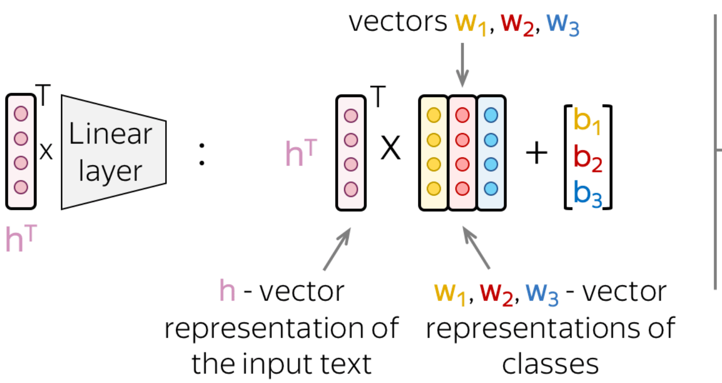
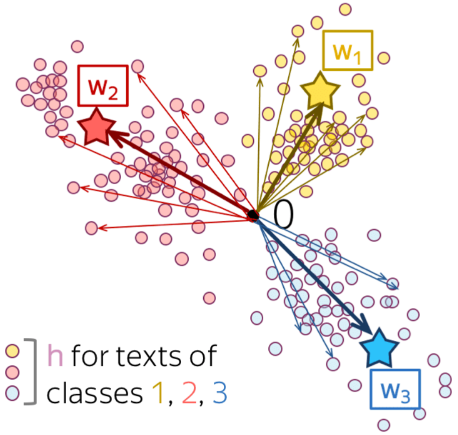
# Overview of DL-based approaches




What NN learns (hopefully):

Text vectors point in the direction of the corresponding class vectors

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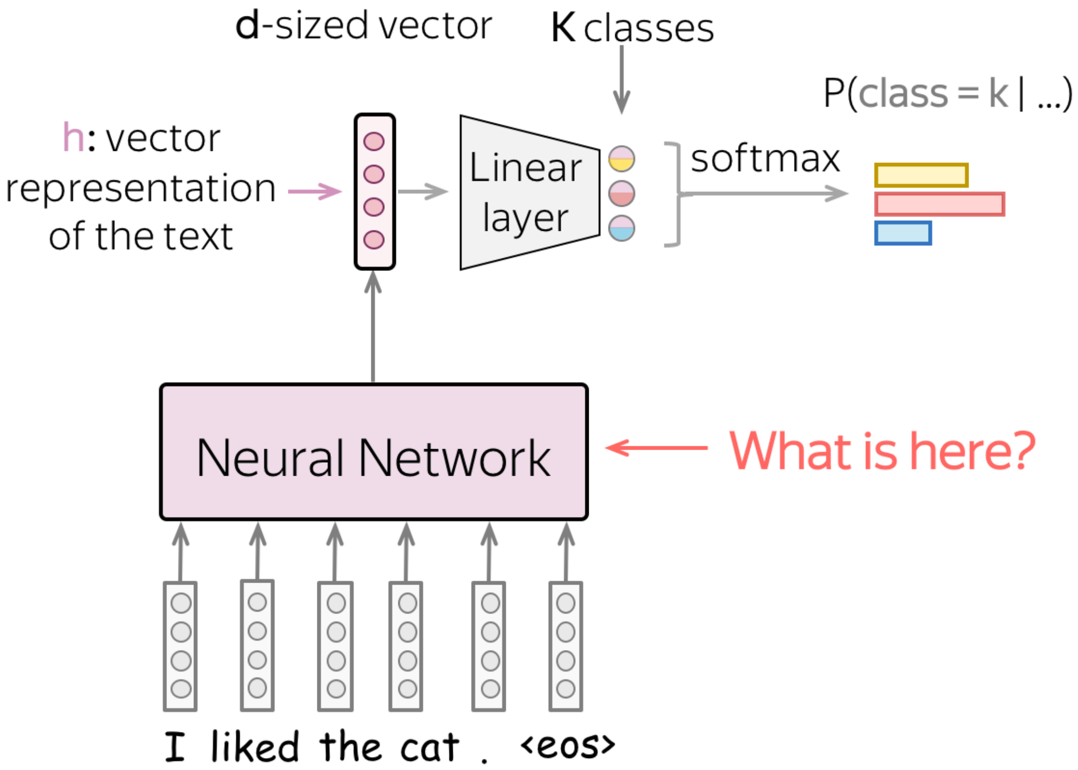
# Overview of DL-based approaches

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- **Deep learning approaches: Basics**
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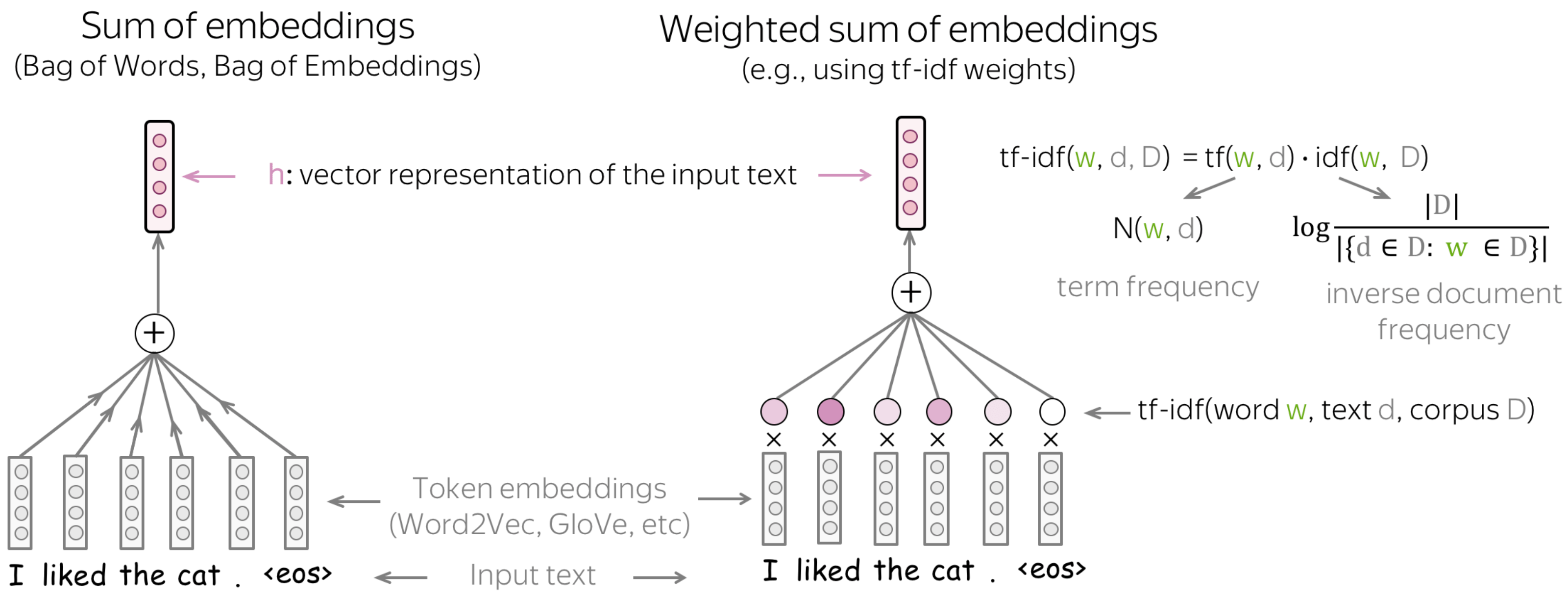
# Vanilla embeddings

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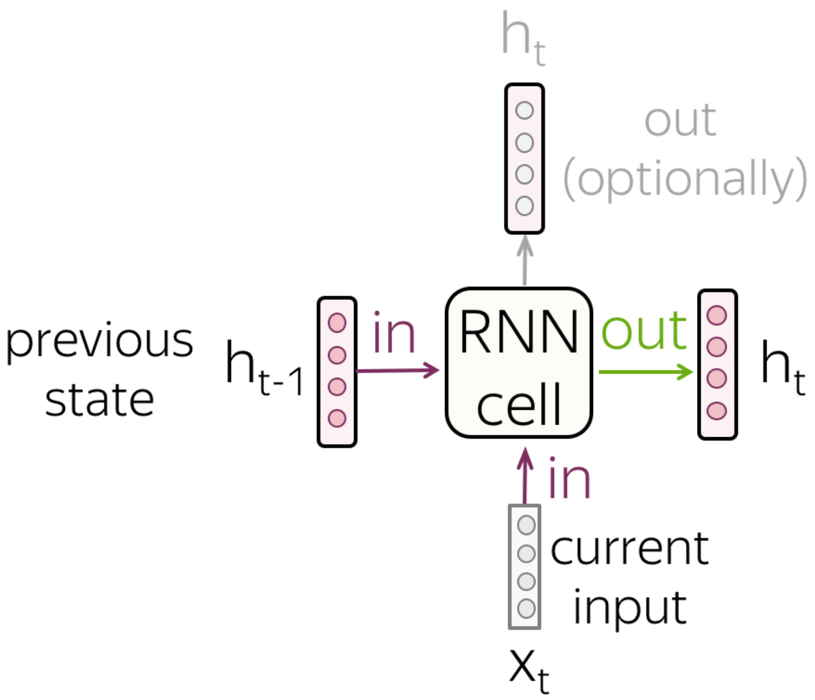
# Vanilla embeddings

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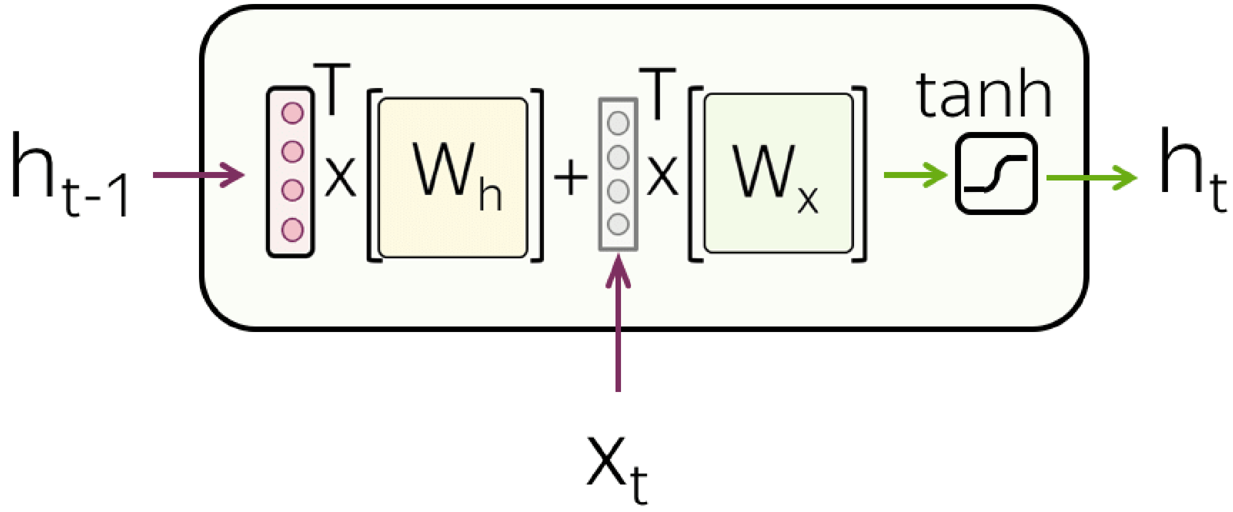
# Vanilla RNN

$$h_t = \tanh(h_{t-1}W_h + x_t W_x)$$

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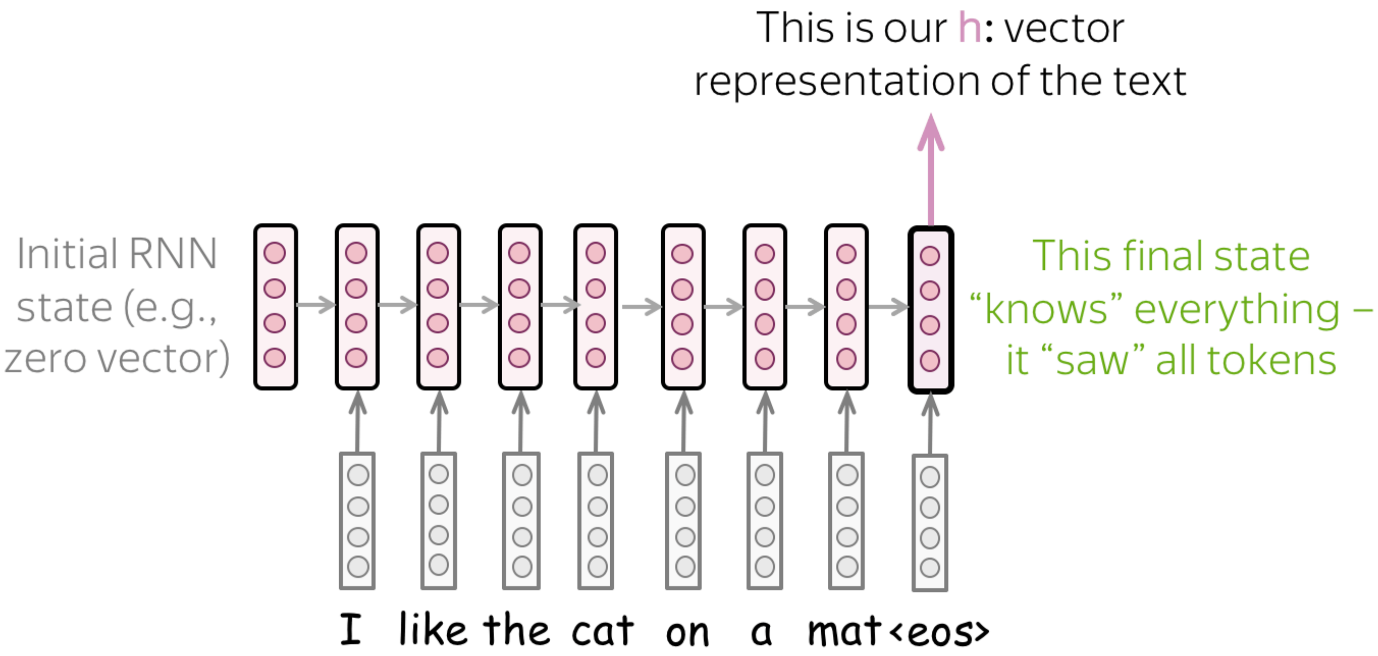
# Vanilla RNN

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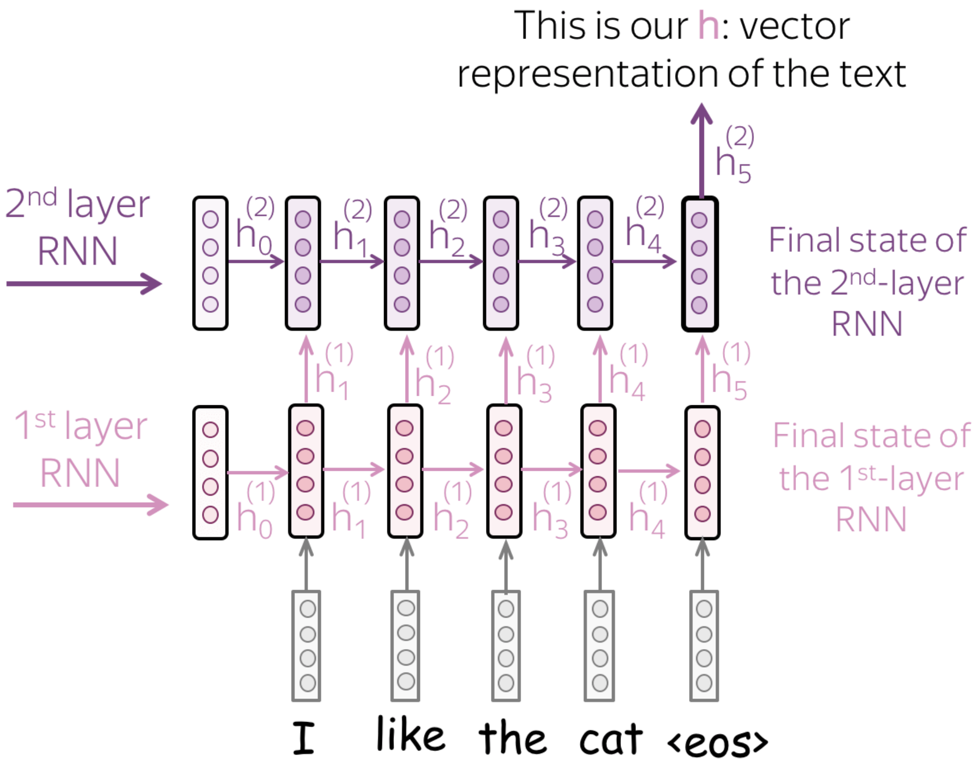
# Stacked RNN

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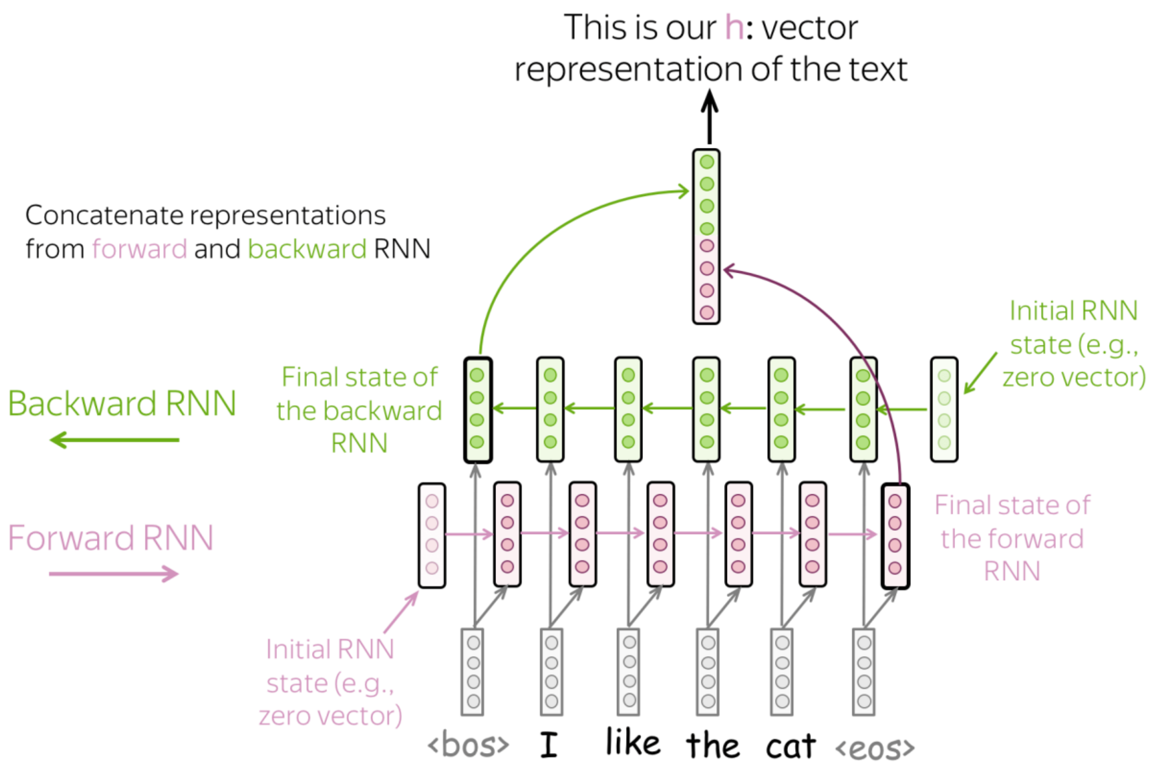
# Bidirectional RNN

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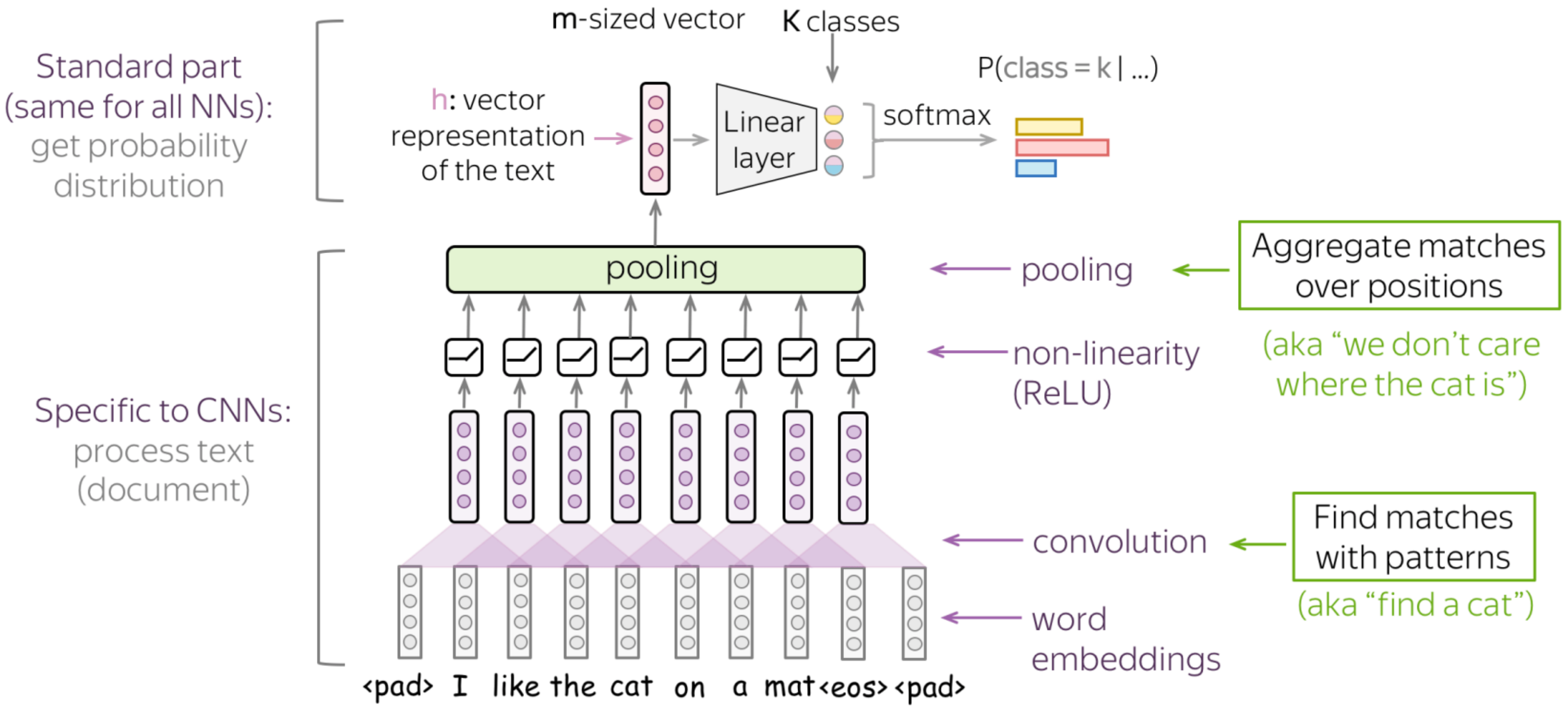
# CNN overview

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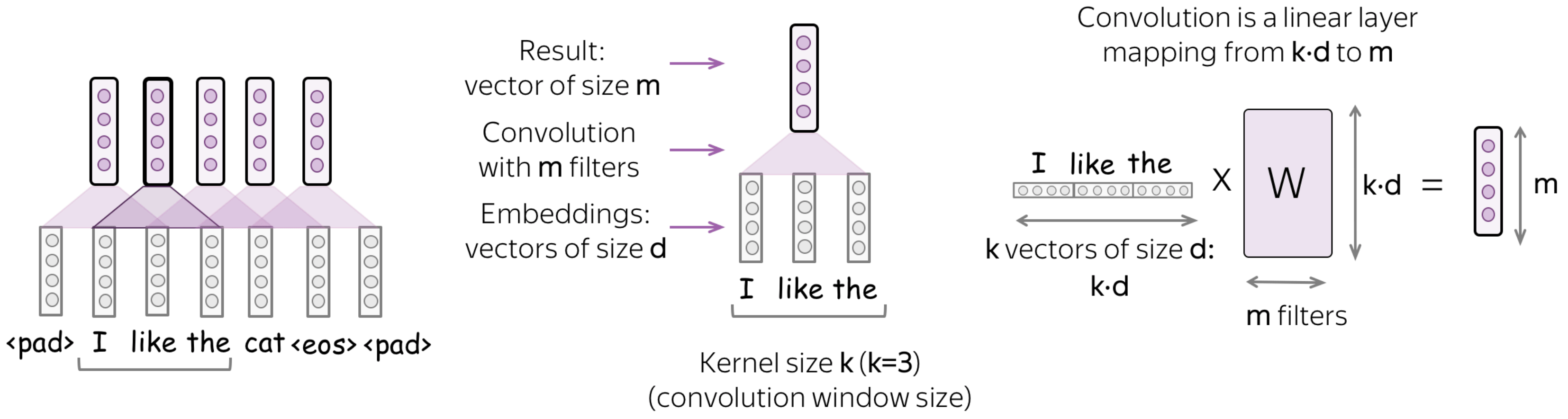
# Convolution is a Linear Operation Applied to Each Window

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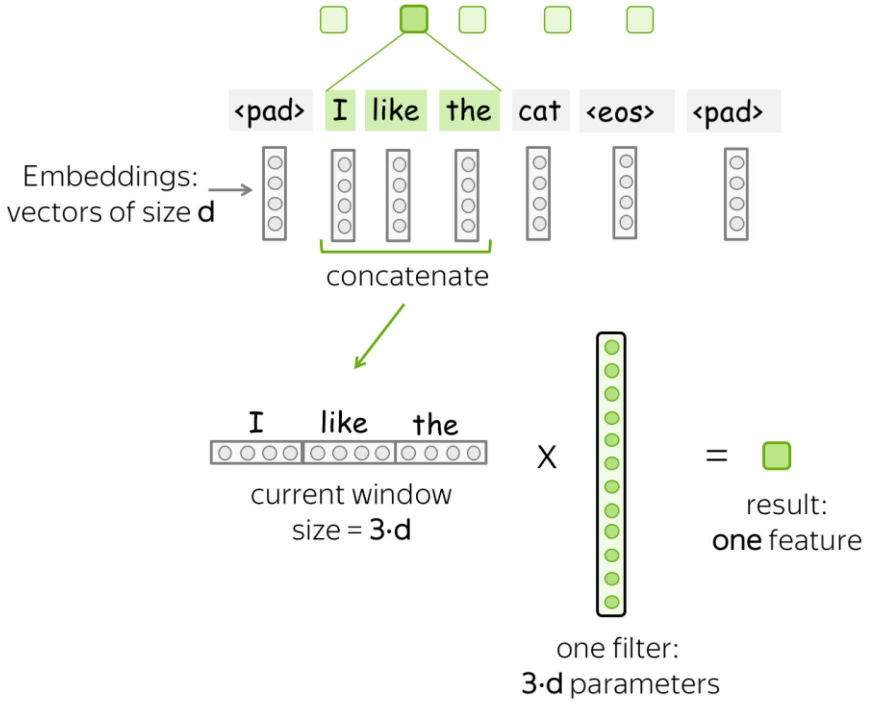
# CNN intuition

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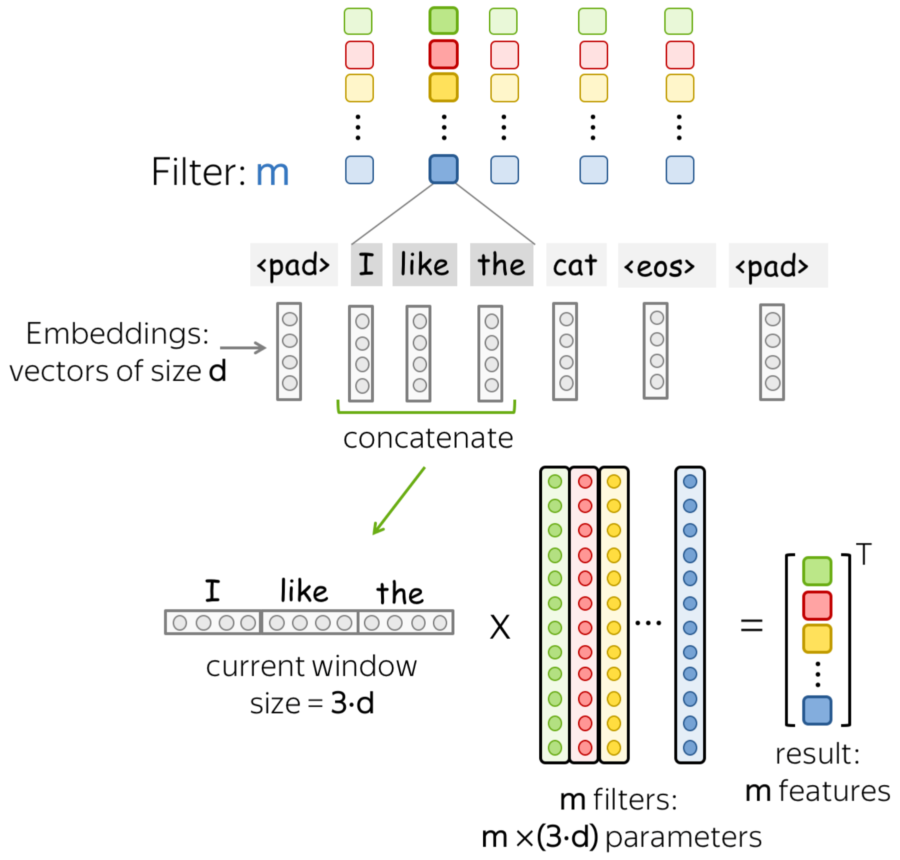
# CNN intuition

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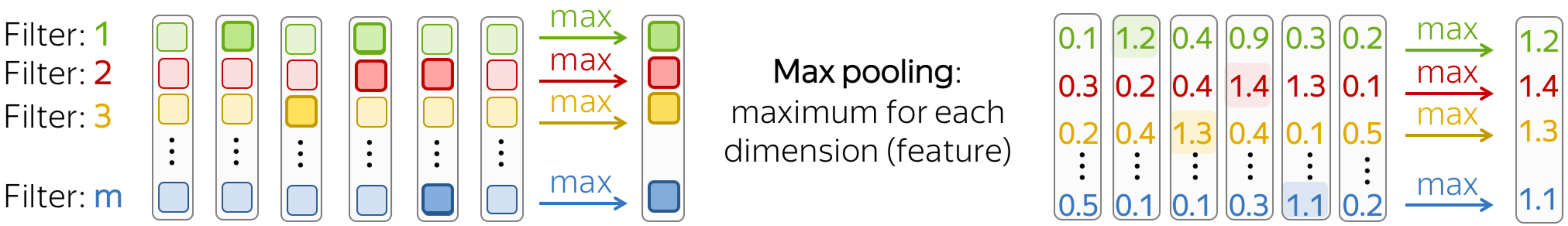
# Pooling

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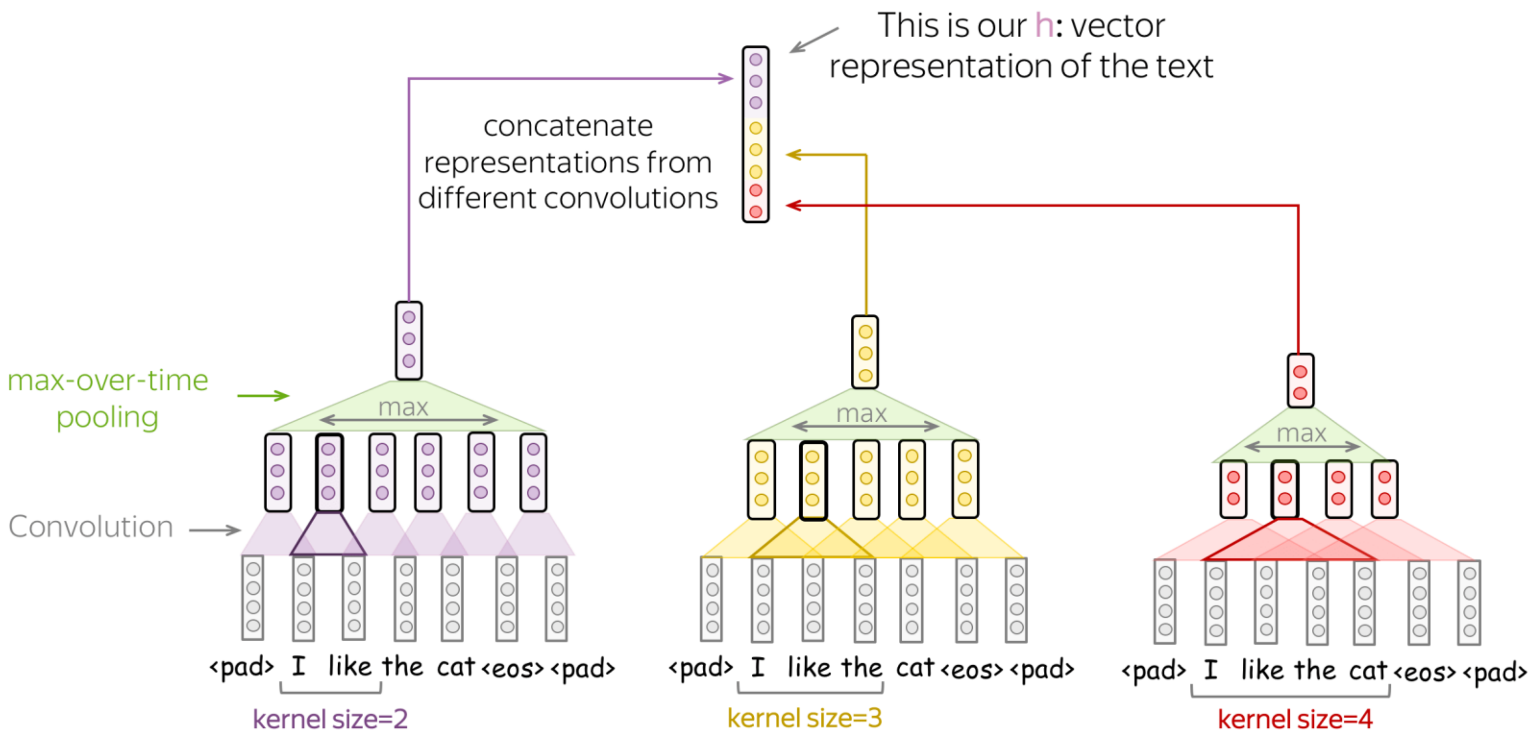
# Larger kernel size for a broader context

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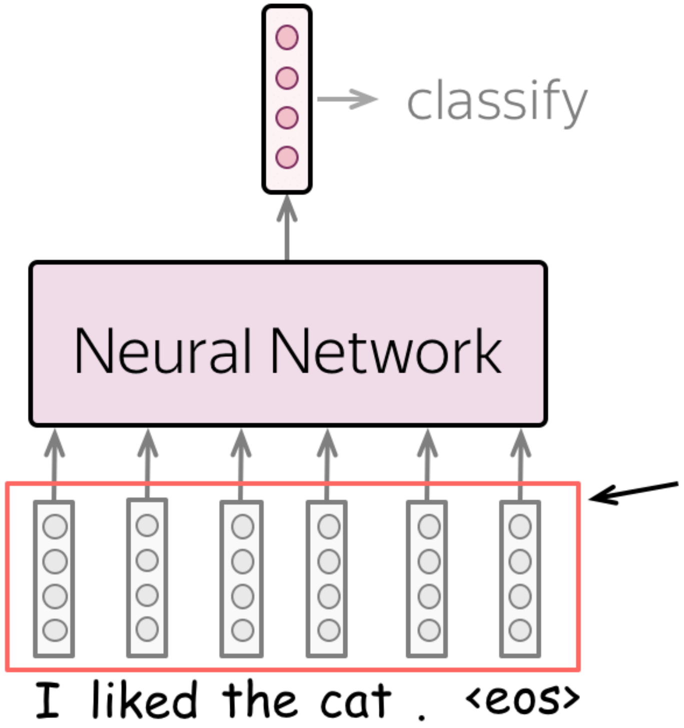
# Larger kernel size for a broader context




**Input word embeddings:**

- Train from scratch
- Take pretrained (Word2Vec, GloVe)
- **Initialize with pretrained, then fine-tune**

Source: https://lena-voita.github.io/nlp_course/text_classification.html

# Data augmentation

The movie about cats was absolutely great, and the cats were cute.

pick several words randomly

replace with UNK

The movie UNK cats was absolutely UNK, and the UNK were cute.

replace with random words

The movie mejorate cats was absolutely fellows, and the mak were cute.

Source: https://lena-voita.github.io/nlp_course/text_classification.html

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