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Deep learning for natural language processing

Workshop @ The Digital Product School / UnternehmerTUM

5.3.2018

From unstructured to structured data

- About me
  - Research focus: Information extraction (IE) from text
  - Currently *Vertretung* for Hinrich Schütze in Munich
- Most information about real world is unstructured.
  - *"At the age of 19, Martin Luther entered the University of Erfurt."* *"On 2 July 1505 he was returning to Erfurt after visiting his parents in Mansfeld."*

  ⇒ Did Martin Luther live in Erfurt?
- Turning unstructured data into structured form:

  Automated knowledge base population (KBP)

  ⇒ `lived_in(M_Luther, Erfurt) 0.8942`

Why more structured data?

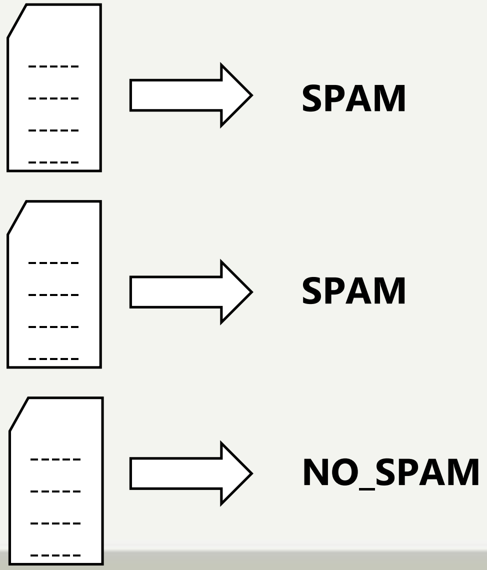
- Algorithms need structured data with specific interpretation
  - Databases, triple stores, ...
  - Hadoop, Spark, ...
- Computer science ⇔ other disciplines:
  - **Computational social science:** Detecting real world conflict and political events [O'Connor, 2013]
  - **Bio-informatics:** Extracting genome and protein interactions from research publications [Segura-Bedmar et al., 2013]
  - **Market research:** Extracting typical use-cases of food and products [Wiegand et al., 2012].
  - ...

Deep Learning for NLP

What is machine learning?

Supervised learning:

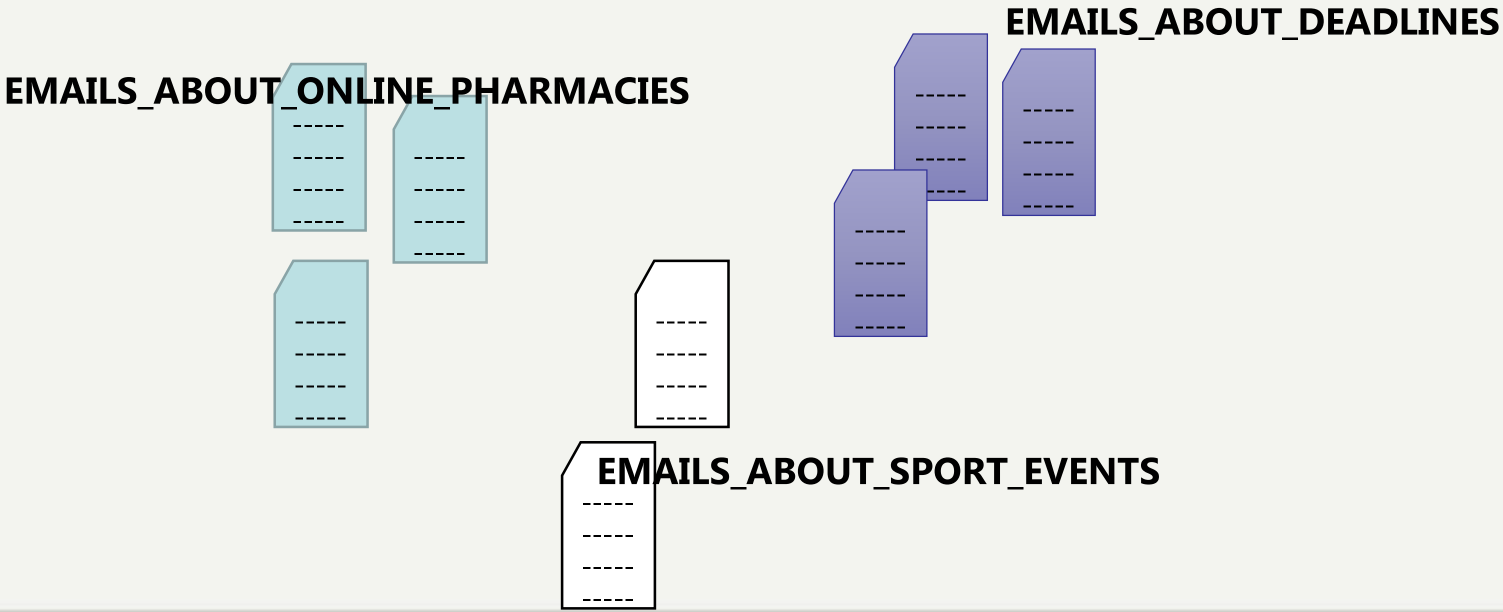
- **``Given X predict Y‘‘**
- **``What is input, what is output?‘‘**
- Most common setting in machine learning
- Needs training data with known output
- **Example:** Is an email (``input‘‘) spam or not (``output‘‘)?



What is machine learning?

Unsupervised learning:

- **Find structure in data** (e.g. groups of similar items)
- Only ``input'' needed, no ``output''
- Useful for helping supervised tasks, or for human data exploration
- **Example**: Find groups of similar emails

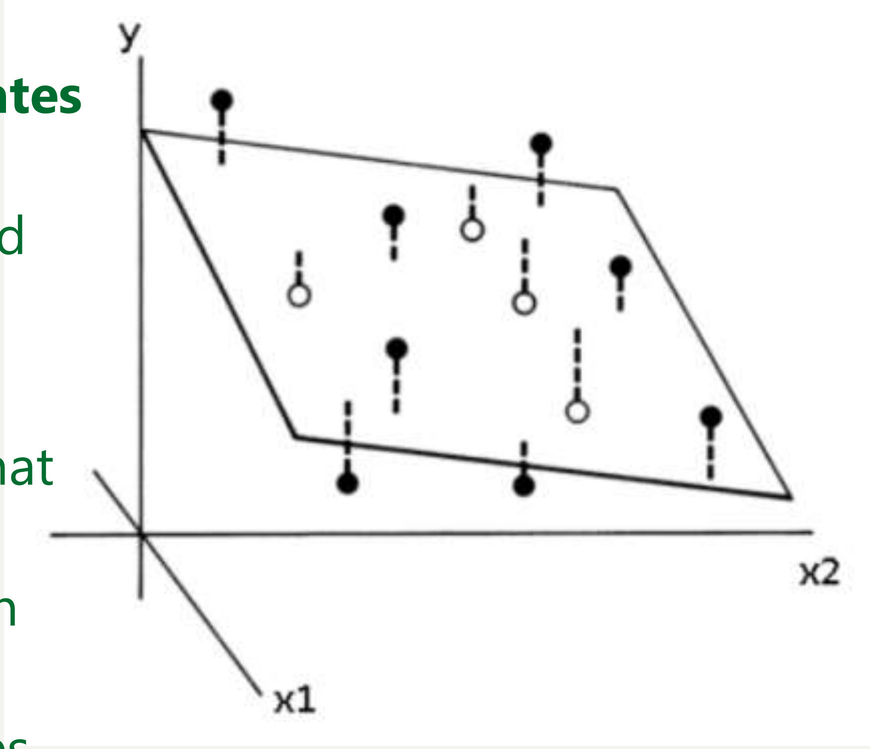


Feature-based learning

- Input representation: explicit set of features (e.g. set words in an email)
- Learn a **prediction rule that operates directly on features**
- Features themselves are not learned
- Prediction rule often **linear**

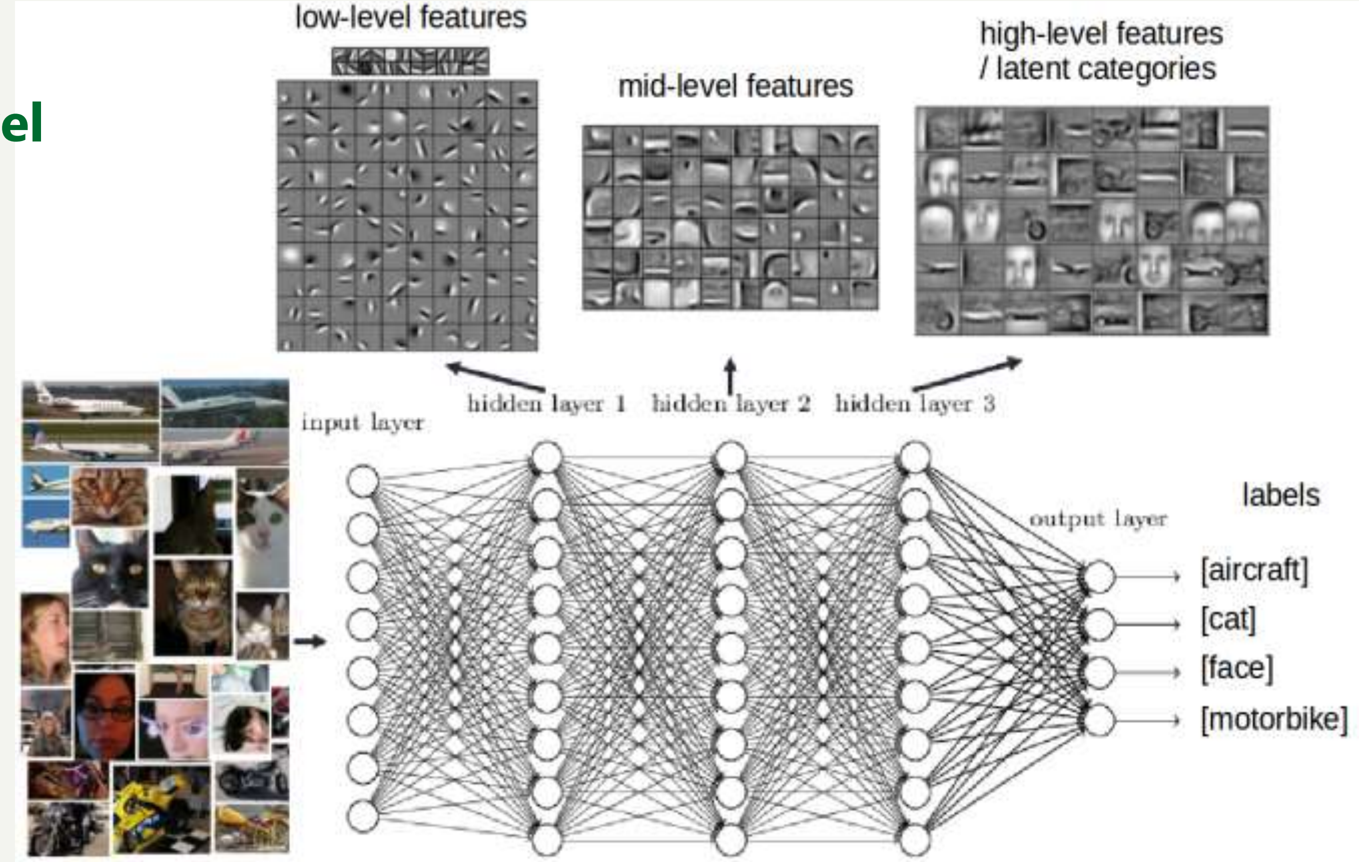
Linear:

- ``More of this feature → More of that output''
- Cannot model interactions between features
- Cannot model saturation of features
- Perceptron, linear SVM, logistic regression, classical CRF,…



Representation learning = Deep Learning = Neural Networks

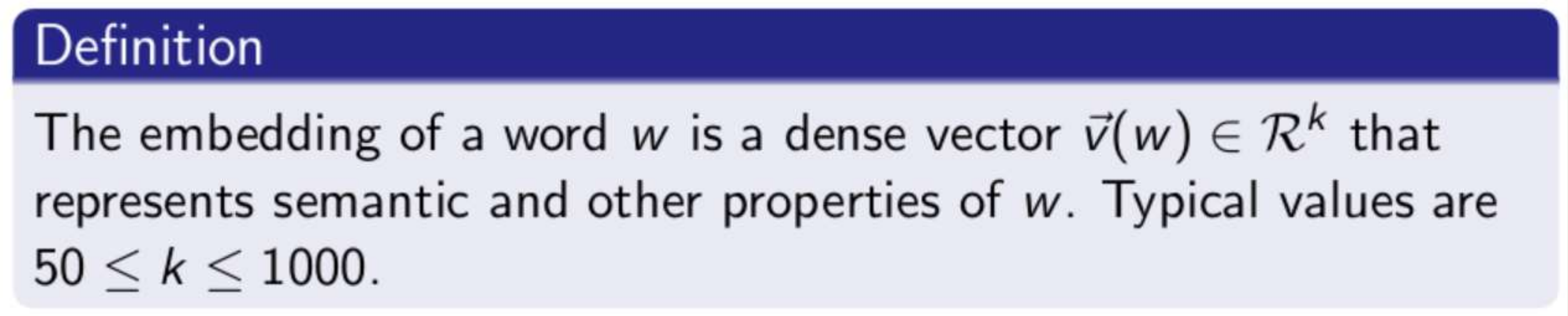
- **Raw input** instead of defined feature representation:
  - Text: Sequence of words or characters
  - Images: Pixels
- **Learn higher-level abstractions**



Representation learning = Deep Learning = Neural Networks

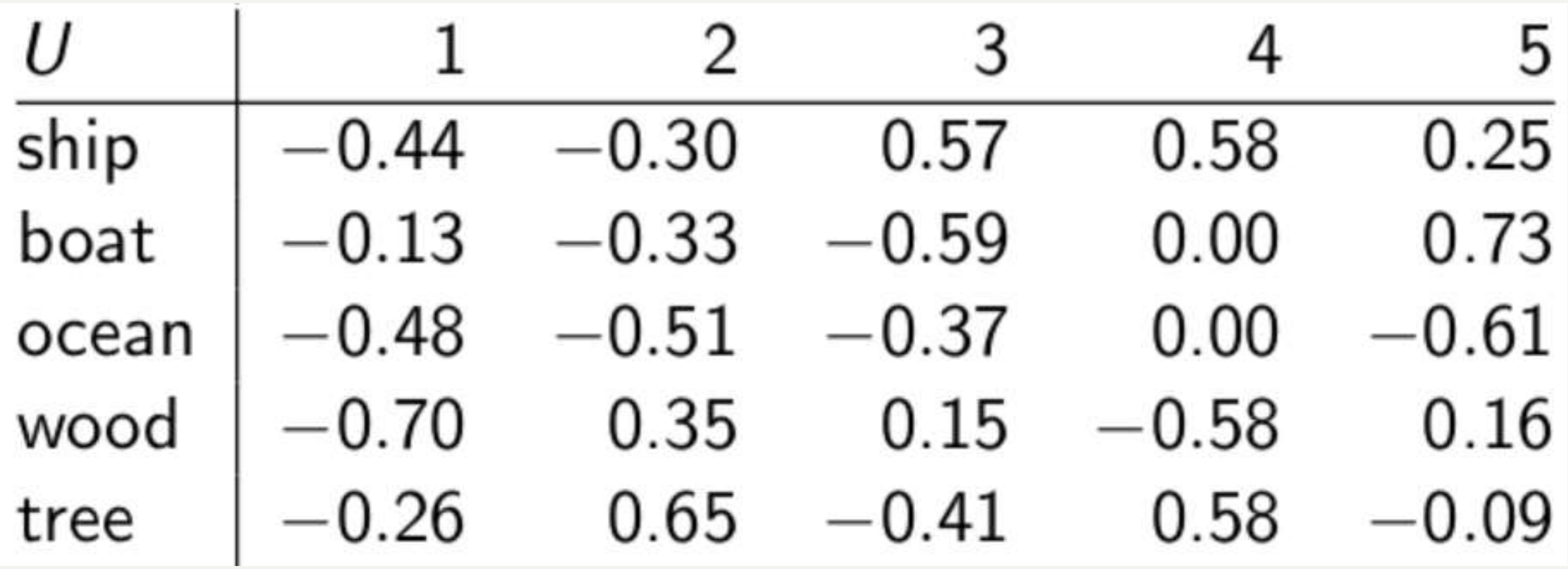
- **Raw input** instead of defined feature representation:
  - Text: Sequence of words or characters
  - Images: Pixels
- **Learn higher-level abstractions**
  - **Non-linear functions** can model interactions of lower-level representations
  - E.g.:
    ``The plot was **not** particularly **original**.'' → **negative** movie review
- Typical setup for natural language processing (NLP)
  - Model starts with learned representations for words
    → **word vectors**
  - Word vectors are combined to represent larger units (sentences, documents)

Word Vectors = Embeddings



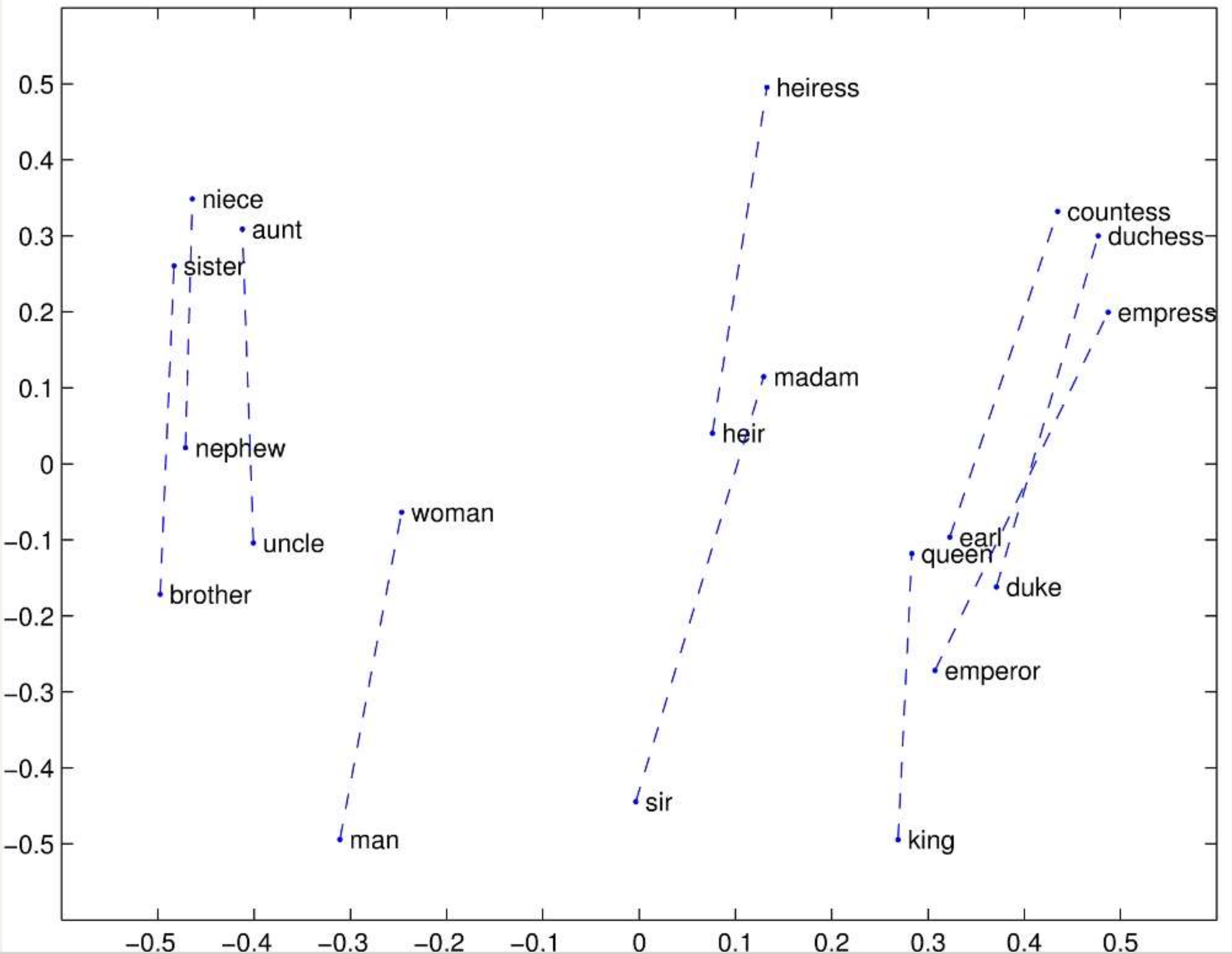
Definition

The embedding of a word w is a dense vector $\vec{v}(w) \in \mathcal{R}^k$ that represents semantic and other properties of w. Typical values are $50 \leq k \leq 1000$.



U	1	2	3	4	5
ship	−0.44	−0.30	0.57	0.58	0.25
boat	−0.13	−0.33	−0.59	0.00	0.73
ocean	−0.48	−0.51	−0.37	0.00	−0.61
wood	−0.70	0.35	0.15	−0.58	0.16
tree	−0.26	0.65	−0.41	0.58	−0.09

Word vectors – regularities in vector space (2D projection)



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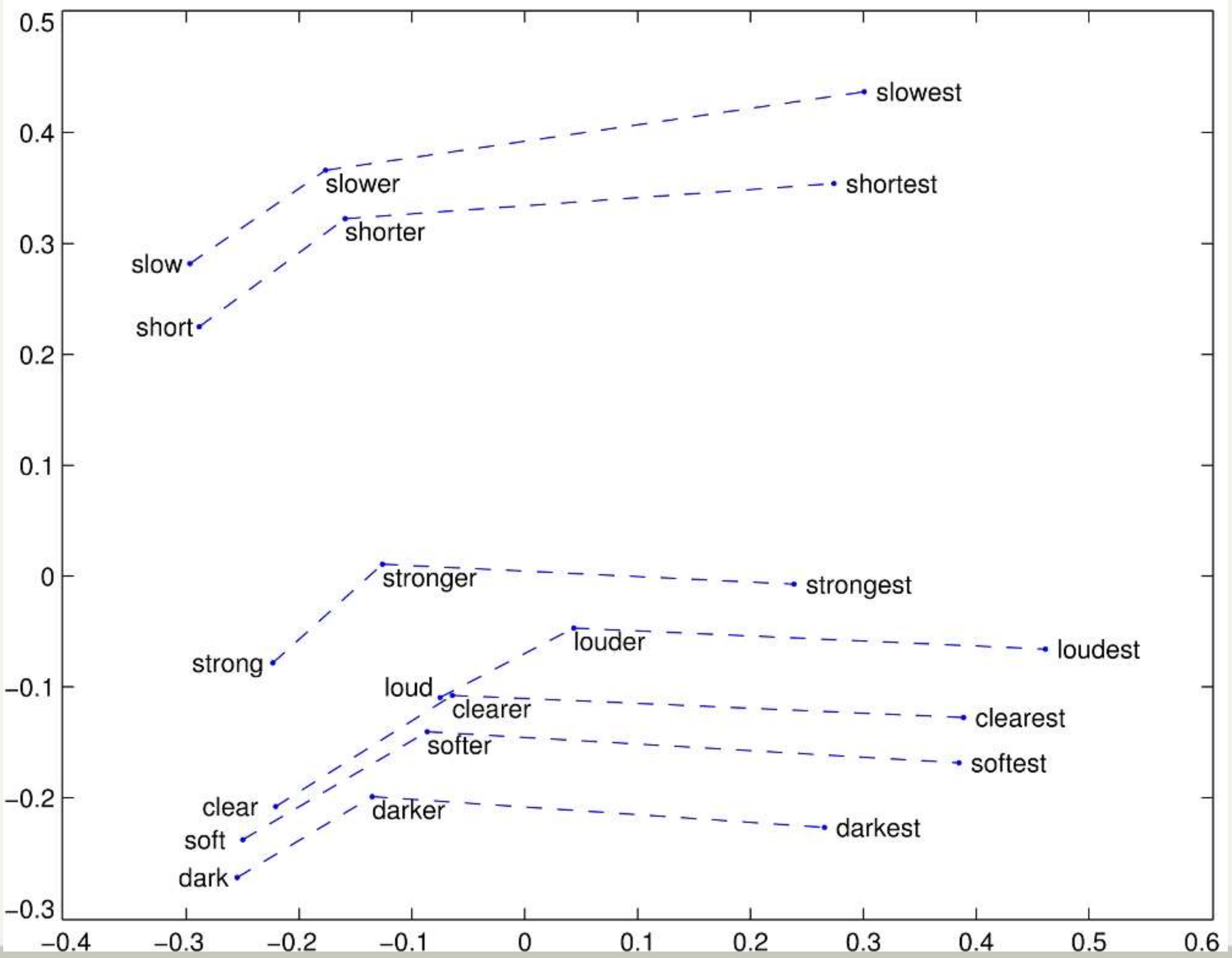
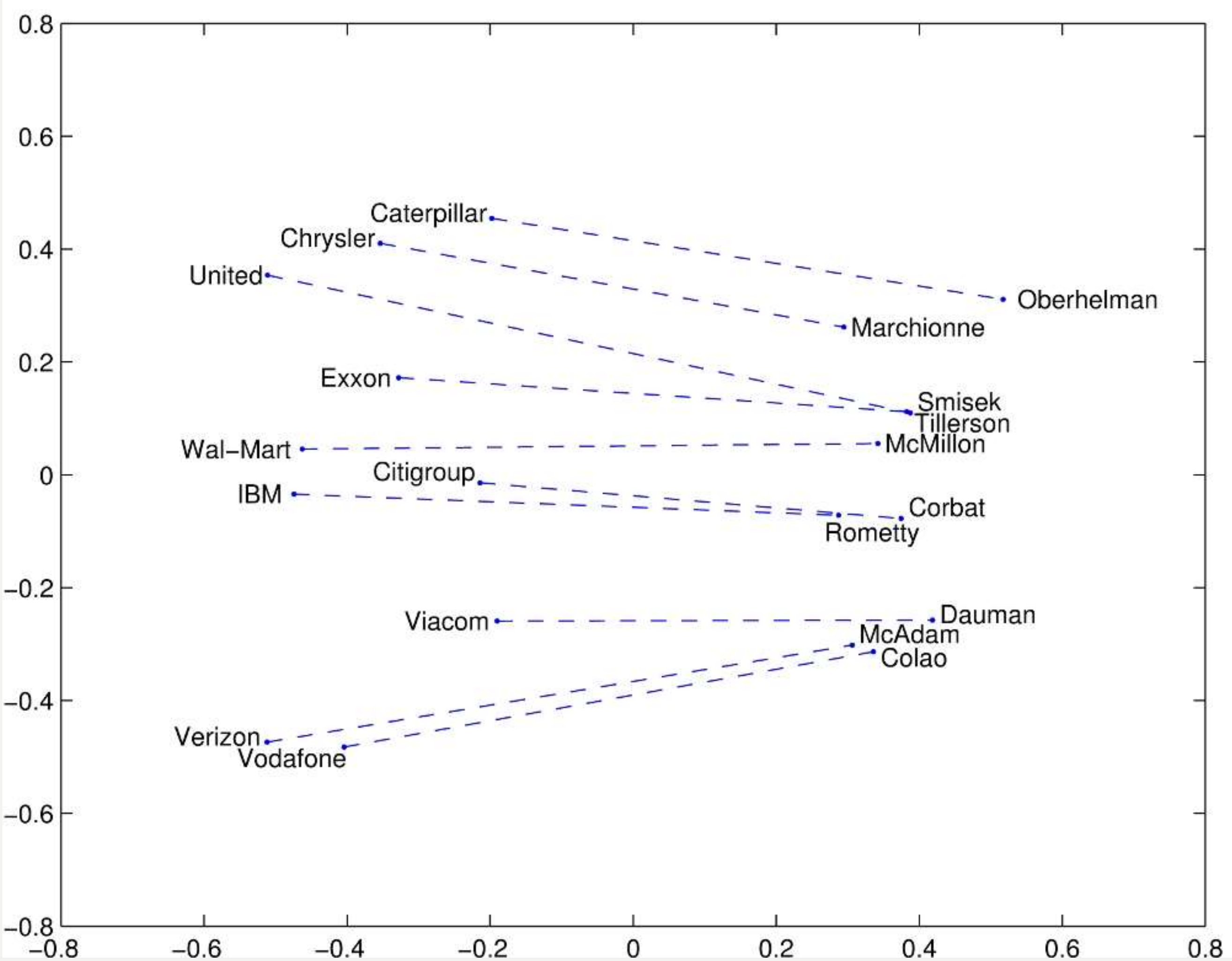


Word vectors – regularities in vector space (2D projection)



Machine Learning as a black box

- ``Given X predict Y''
- ``What is input, what is output?''
- What is input?
    - Text: a sequence of tokens (sentence or document)
- What is output?

Machine Learning as a black box

- What is input?
  - Text: a sequence of tokens (sentence or document)
- What is output?
  - One of several categories (*Classification*)

    → **Spam / no spam**
  - A numerical value (*Regression*)

    → **Number of stars** given a review
  - A prediction for each token (*Tagging*)

    → Mark each word that is a **person, location or organization**
  - Another text (*Sequence-to-sequence*)

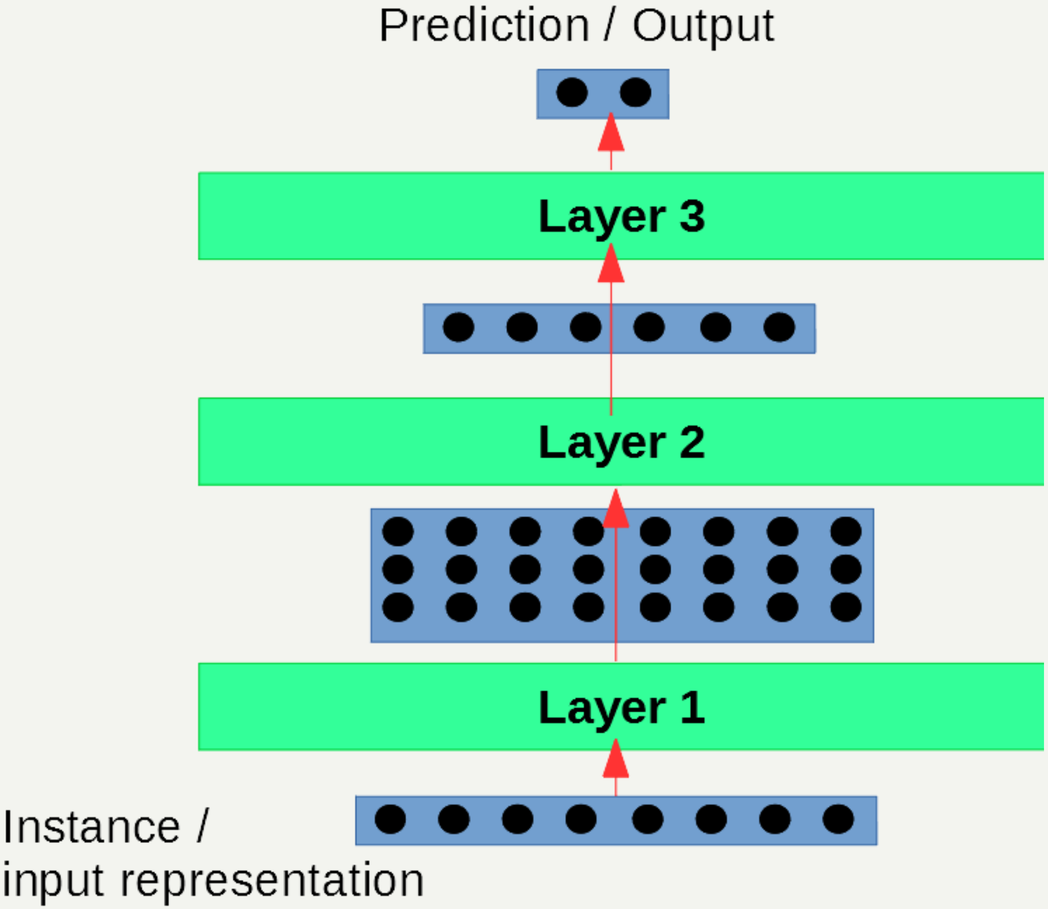
    → **Translation** of sentence into a different language

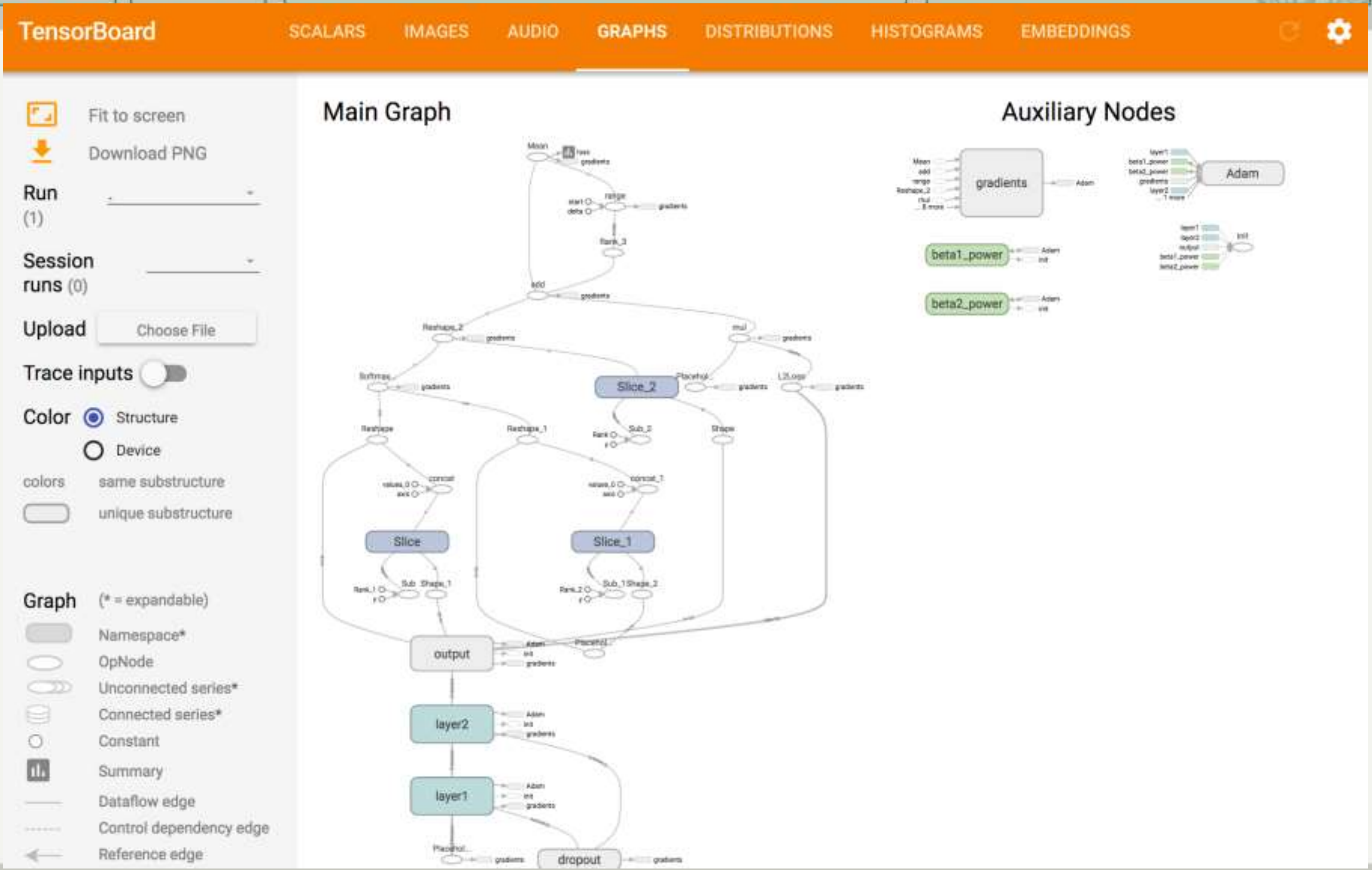
Deep learning and modularization

- Deep learning models for NLP
  - Modul 1: **Encode sentence**
    - Result: Vector representation with learned features
  - Modul 2: **Make prediction**
    - Input: Learned Features
- ***Deep learning provides an API for machine learning***
  - A main advantage, even if sometimes traditional models perform equally well
- ***Interfaces are learned vector representation***
  - input → vector(s)
  - vector(s) → vector(s)
  - vector(s) → output

Layers

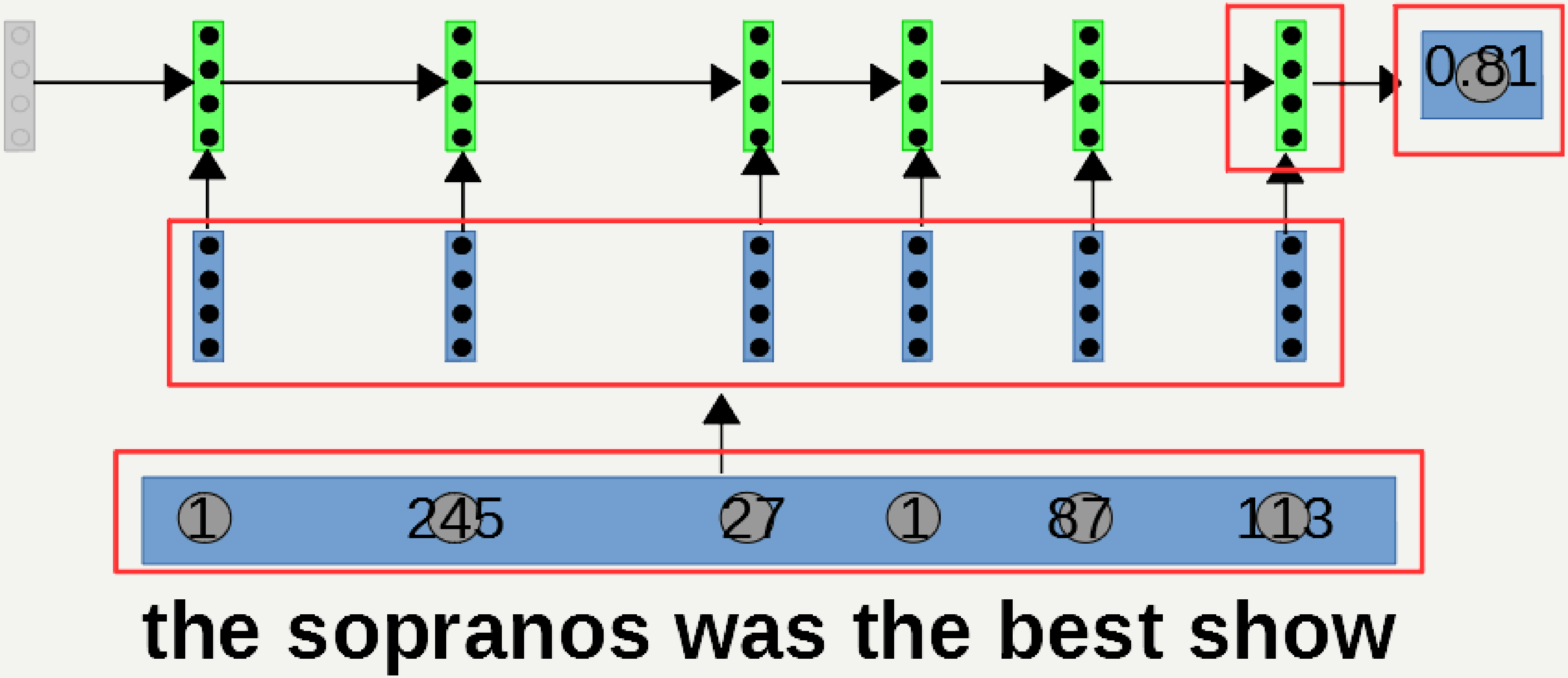
- A neural network consists of different **layers: Mappings from vectors to vectors**
- The output of one layer is the input to the next layer
- Input and output dimensions do not need to match
- **First layer is word vector lookup**
- **Last layer is prediction**





Color: ● Structure ○ Device

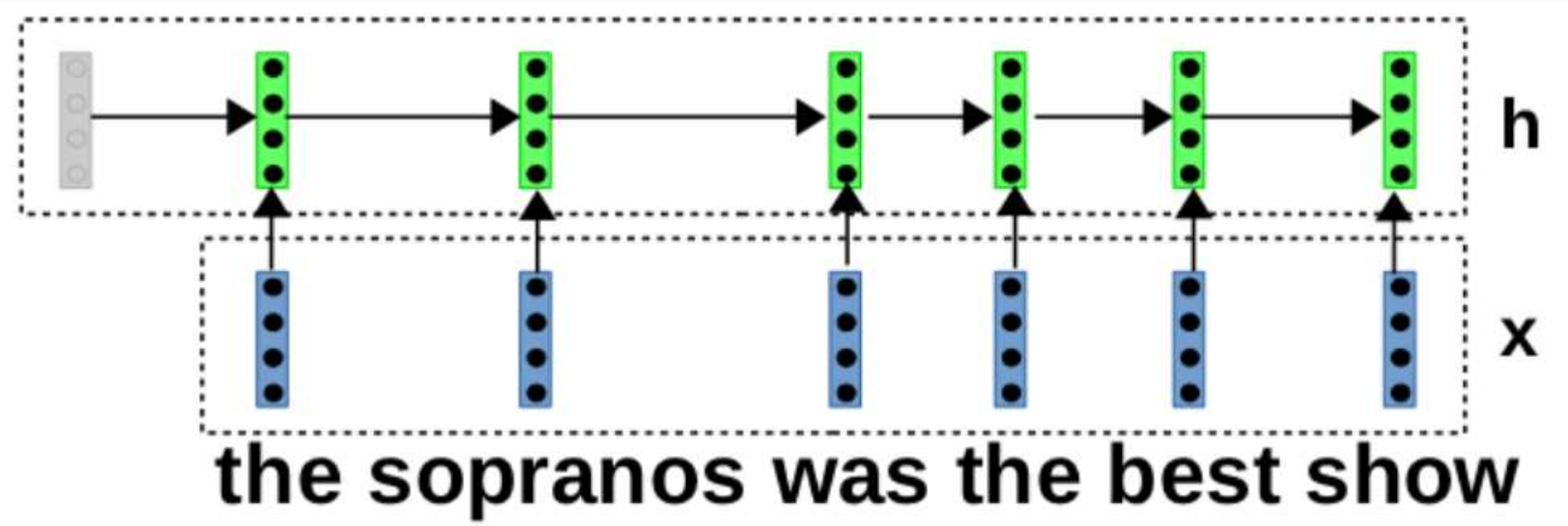
Layers in a neural network for sentiment prediction



Recurrent Neural Networks (RNNs)

- A sentence is recursively summarized by a non-linear function that **combines** current **word vector** with the **summary at the previous position**

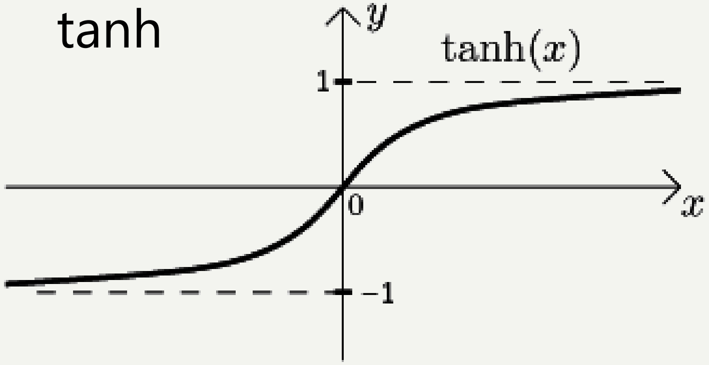
$$\mathbf{h}^{(t)} = f(\mathbf{h}^{(t-1)}, \mathbf{x}^{(t)})$$
$$= \sigma(\mathbf{W}[\mathbf{h}^{(t-1)}; \mathbf{x}^{(t)}])$$



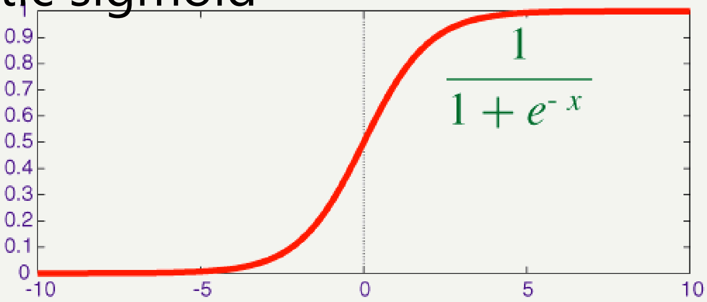
The most popular variant of RNNs is the LSTM (Long Short-Term Memory network).
It has advantages when training with long sequences.

Common non-linearities

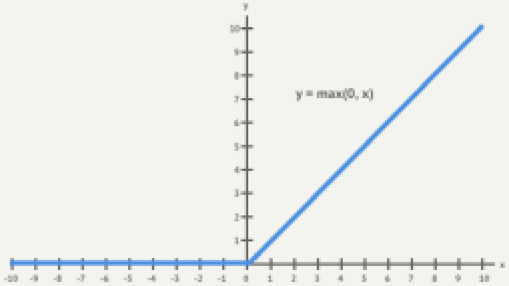
tanh



logistic sigmoid



ReLu

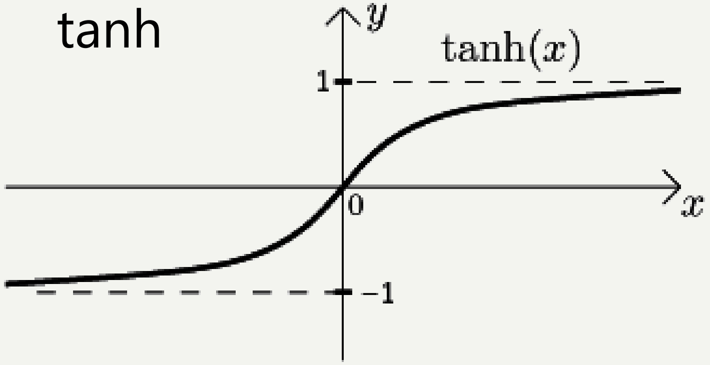


softmax

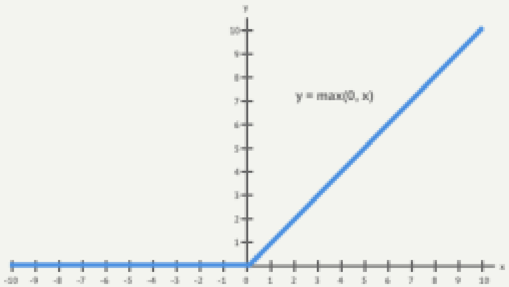
$$y_i = \frac{e^{(x_i)}}{\sum_j e^{(x_j)}}$$

Common non-linearities

tanh

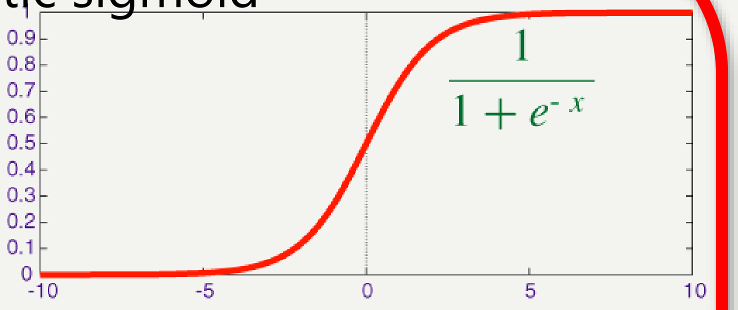


ReLu



used for last layer / prediction

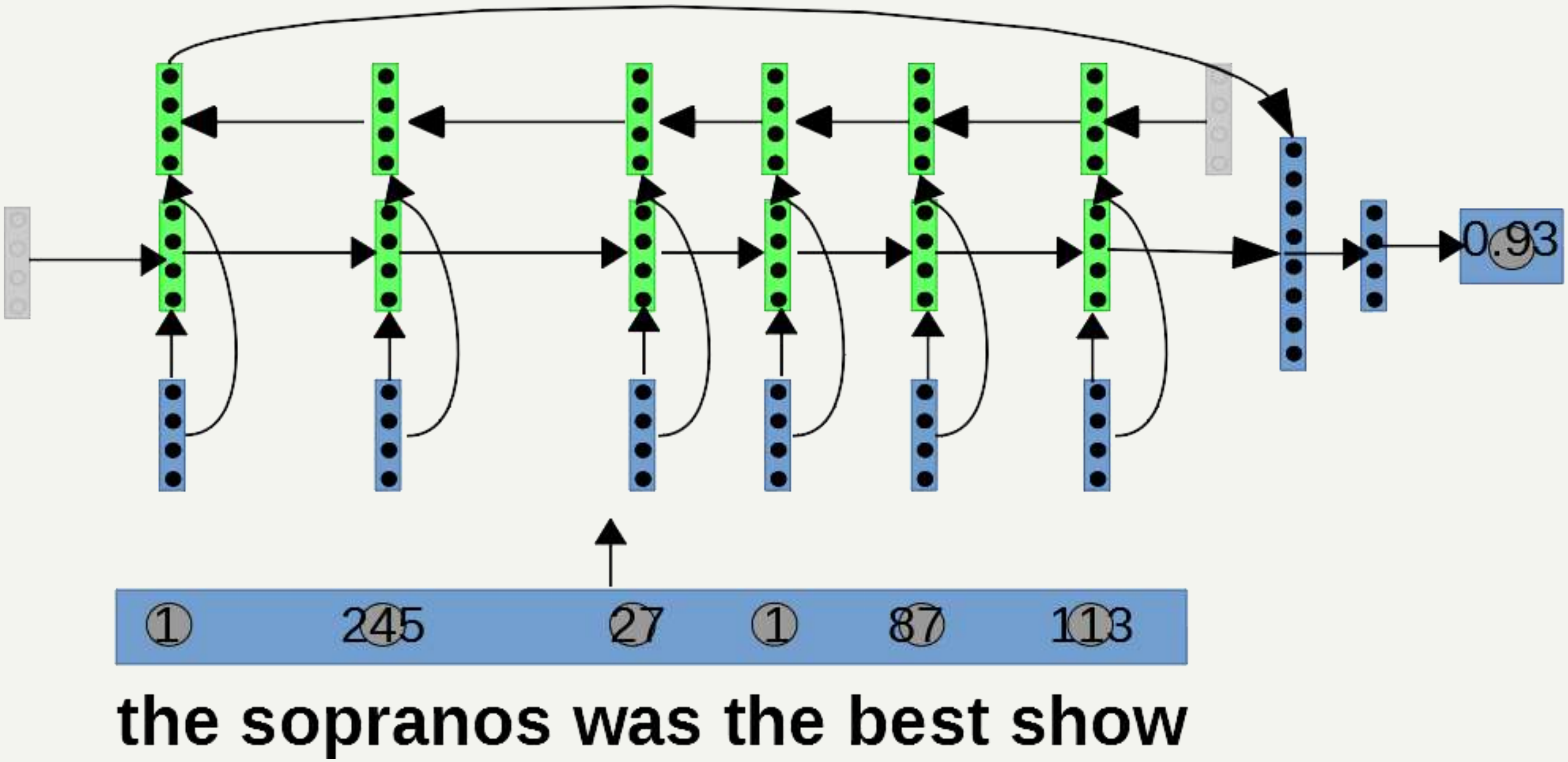
logistic sigmoid



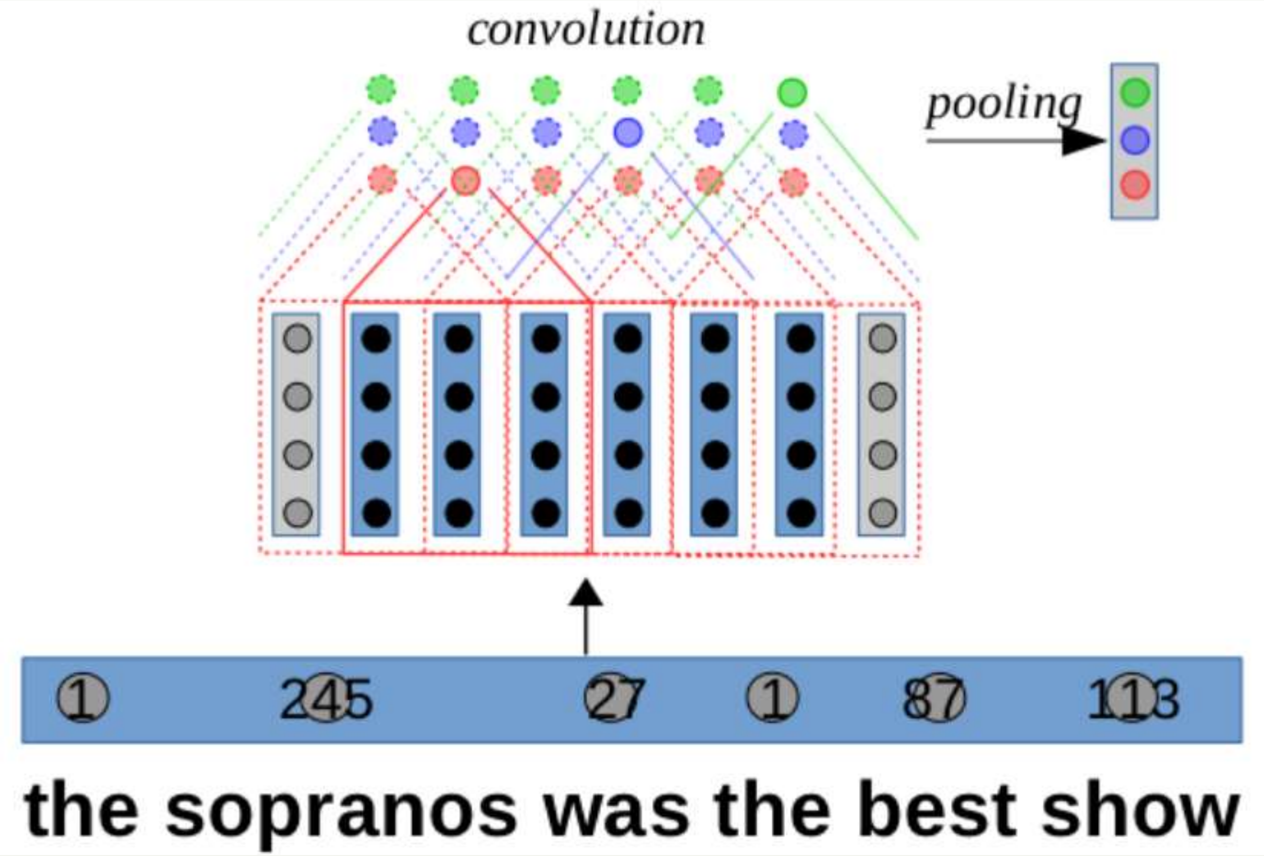
softmax

$$\mathbf{y_i} = \frac{e^{(x_i)}}{\sum_j e^{(x_j)}}$$

The state of the art for many applications: Bidirectional LSTMs



Convolutional Neural Networks (CNNs)



Deep learning and modularization

- **General purpose mechanisms …**
  … independent of specific problem
- Optimal parameters learned from a task-specific training corpus
- For example: **Mechanisms to encode a sequence**
  - Recurrent Neural Networks (RNN, LSTM/GRU, QLSTM/QGRU)
  - Convolutional Neural Networks (CNNs)
  - Self-Attention, …
- **Mechanism to produce an output** depend on the task
  - E.g. multiclass prediction: Softmax
  - E.g. tagging: Neural Conditional Random Fields
  - …

Deep learning and modularization

- Interfaces are learned vector representation
  - input → vector
  - vector(s) → vector
  - sector → output
- Learned vector representations as the universal ``language'' of neural networks
- Makes it easy to
  - Combine different input modalities (e.g. audio+video+subtitles)
  - Pre-train parts of the architecture (e.g. word vectors, sentence encoder)
  - Predict different outputs from the same representation

Deep learning and modularization

Deep learning provides a modular way of structuring your problem.

Example Problem: Question Anwering

Text: *``Yesterday, Emanuel Macron and his wife Brigitte Trogneux visited the Louvre Abu Dhabi Museum´´*

Question: *``Who is Emanuel Macron married to?´´*

Answer: *``Brigitte Trogneux´´*

- **What is input?** How to encode input?
- **What is output?** Task type?
  - Classification?
  - Regression?
  - Tagging?
  - Sequence-to-sequence?

Example Problem: Question Anwering

Text: *``Yesterday, Emanuel Macron and his wife Brigitte Trogneux visited the Louvre Abu Dhabi Museum´´*

Question: *``Who is Emanuel Macron married to?´´*

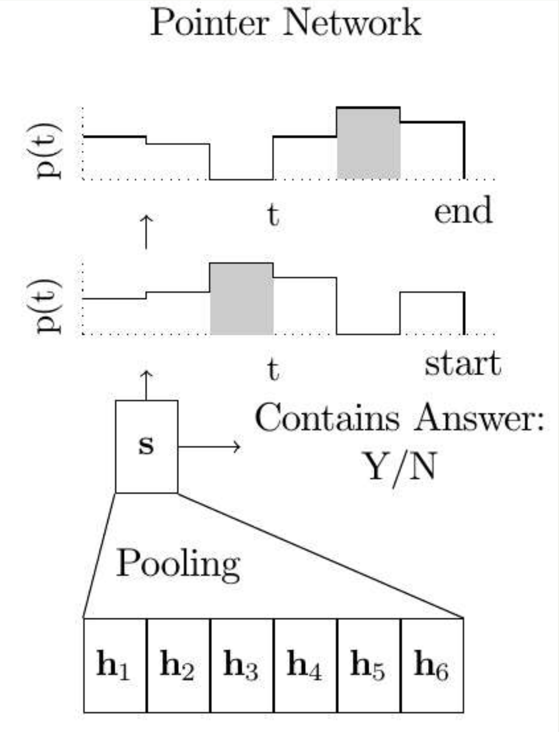
Answer: *``Brigitte Trogneux´´*

- **What is input?**
  - Question + sentence
- How to encode input?
  - Concatenate question and sentence
    `Who is Emanuel Macron married to? # Yesterday, Emanuel Macron and his wife Brigitte Trogneux visited the Louvre Abu Dhabi Museum`
  - Encode question, encode sentence, and concatenate vectors
  - Attention mechanisms (BiDAF), …

Example Problem: Question Anwering

Question: *``Who is Emanuel Macron married to?´´*

- **What is output?**
  - Answer = substring of text
    Yesterday, Emanuel Macron and his wife ***Brigitte Trogneux*** *visited the Louvre Abu Dhabi Museum*
- Task type?
  - Predict start and end positions of answer. (Classification/Regression)



Example Problem: Question Anwering

Question: *``Who is Emanuel Macron married to?´´*

- **What is output?**
  - Answer = substring of text
    *Yesterday, Emanuel Macron and his wife **Brigitte Trogneux** visited the Louvre Abu Dhabi Museum*
- Task type?
  - For combinations of start and end positions, predict whether subspan is answer. (Classification)

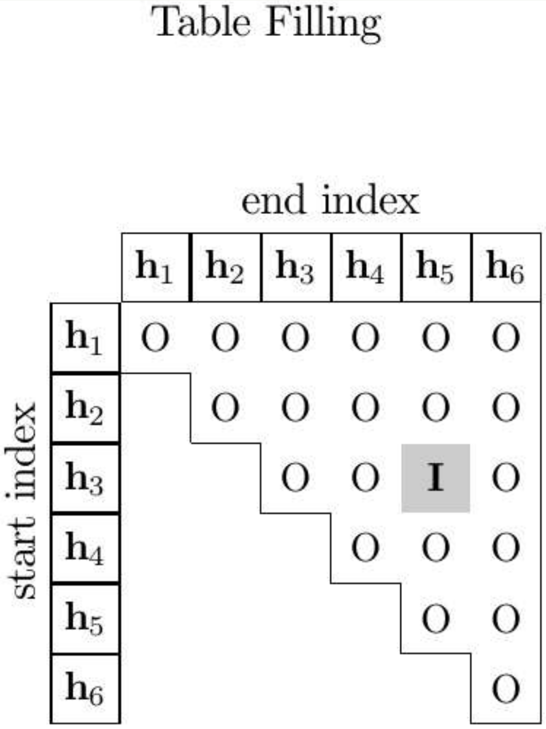


Table Filling

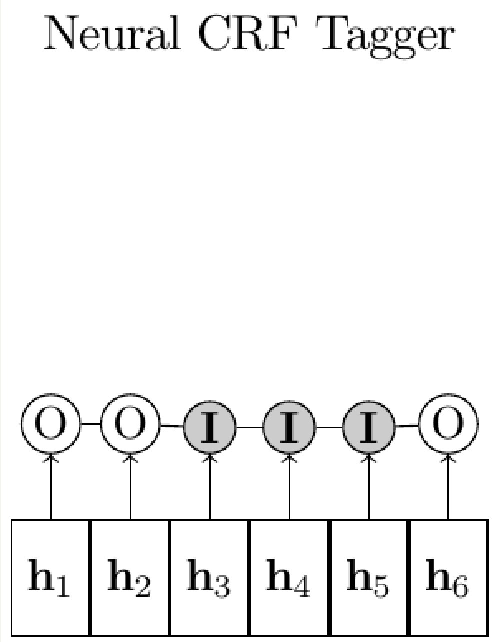
end index

start index	$\mathbf{h}_1$	$\mathbf{h}_2$	$\mathbf{h}_3$	$\mathbf{h}_4$	$\mathbf{h}_5$	$\mathbf{h}_6$
$\mathbf{h}_1$	O	O	O	O	O	O
$\mathbf{h}_2$		O	O	O	O	O
$\mathbf{h}_3$			O	O	**I**	O
$\mathbf{h}_4$				O	O	O
$\mathbf{h}_5$					O	O
$\mathbf{h}_6$						O

Example Problem: Question Anwering

Question: *``Who is Emanuel Macron married to?´´*

- **What is output?**
    - Answer = substring of text
      Yesterday, Emanuel Macron and his wife ***Brigitte Trogneux*** *visited the Louvre Abu Dhabi Museum*
- Task type?
    - For each word, mark whether it belongs to the answer (tagging)



Example Problem: Question Anwering

Question: *``Who is Emanuel Macron married to?´´*

- **What is output?**
  - Answer = substring of text
    *Yesterday, Emanuel Macron and his wife **Brigitte Trogneux** visited the Louvre Abu Dhabi Museum*
- Task type?
  - ``Translate´´ question+text into answer (sequence-to-sequence)
  - *Who is Emanuel Macron married to? # Yesterday, Emanuel Macron and his wife Brigitte Trogneux visited the Louvre Abu Dhabi Museum*
    → Brigitte
    → Trogneux
    → <END>

Deep Learning Frameworks

- Specify the model
- Optimize parameters (training)
- Make predictions
- Deploy training and prediction

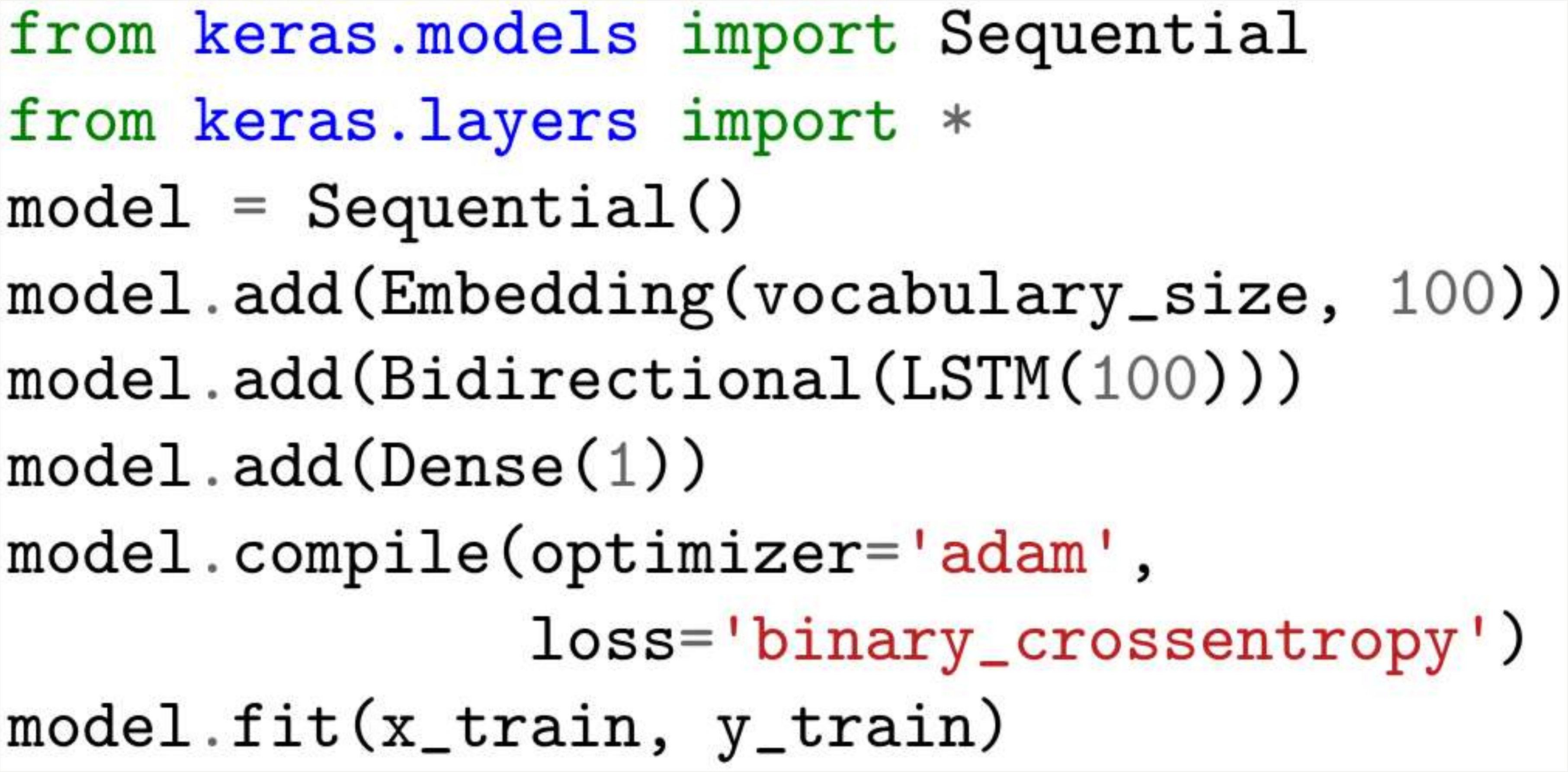
3 Deep Learning Frameworks (Python)

- TensorFlow (2015-)
  - Developed by Google
  - *Static computation graph:*
    model specification → compilation → training/running/debugging
  - Strenghts:
    - Industrial strength deployment options
    - Large community / strong backing
- Keras (2015-)
  - High-level deep learning abstractions
  - Takes away 95% of programming overhead (and some flexibility)
  - Great way to start for standard problems (classification, tagging,…)
  - Since 2017 integrated into Tensorflow core

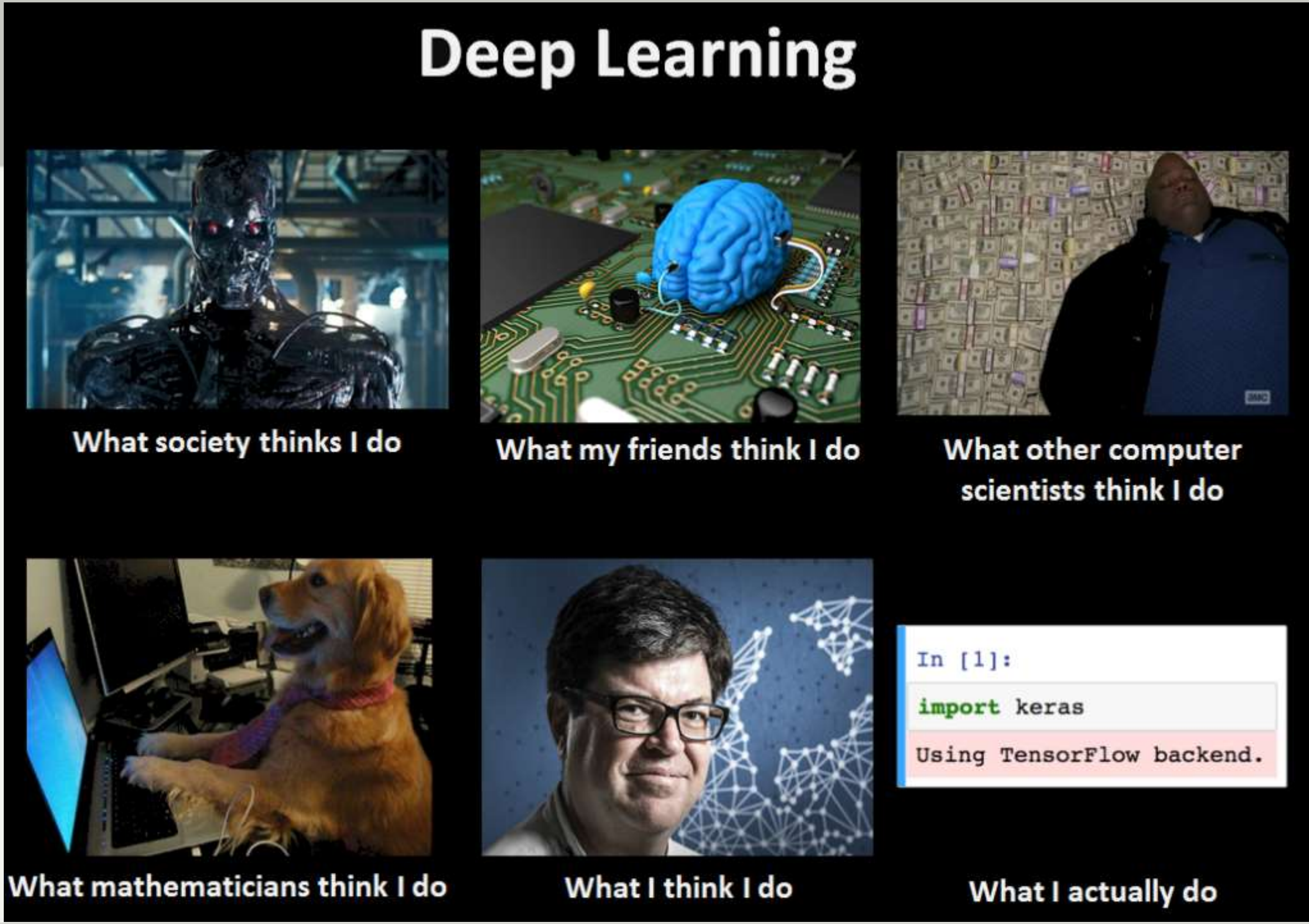
3 Deep Learning Frameworks (Python)

- Pytorch (2016-)
  - Developed by Facebook AI
  - *Dynamic computation graph:*
    model specification=model → training/running/debugging
  - Great for prototyping of novel model types
    - Easy to integrate control flow logic (hierarchical models, reinforcement learning,...)
    - Meaningful debugging output
- There are many more: Theano, CNTK, MXNet, Caffe, …

Building neural networks with Keras



```
from keras.models import Sequential
from keras.layers import *
model = Sequential()
model.add(Embedding(vocabulary_size, 100))
model.add(Bidirectional(LSTM(100)))
model.add(Dense(1))
model.compile(optimizer='adam',
              loss='binary_crossentropy')
model.fit(x_train, y_train)
```



Deep Learning

What society thinks I do

What my friends think I do

What other computer scientists think I do

What mathematicians think I do

What I think I do

```
In [1]:
import keras
Using TensorFlow backend.
```

What I actually do

Q: I want to use deep learning for NLP. Where do I start?

1. Make sure your problem fits into the scheme
   ``Given X predict Y´´ (What is input? What is output?)
2. **Get training data**, i.e. input-output pairs
   - Input alone is not sufficient!
   - Collect data (e.g. from observed user behavior)
   - Annotation, crowd-sourcing (Amazon Mechanical Turk) necessary?
   - Automatic labelling possible? (by combining data sources)
   - Rule of thumb: for NLP **at least 10000 training instances** (better: several millions)
3. **Split training data** into three parts
   - Training (80%): used by model training to optimize parameters
   - Development (10%): for monitoring effect of changes to architecture
   - Test (10%): used to detect overfitting on development data

Q: I want to use deep learning for NLP. Where do I start?

4. Determine **task type**
   - Classification?
   - Regression?
   - Tagging?
   - Sequence-to-sequence?
5. Choose **deep learning framework**
   - My recommendation: start with Keras
6. Build architecture
   - Encode text with **bidirectional LSTMs**
   - Encode images with pre-trained architecture (e.g. VGG+Imagenet)
   - Encode simple additional input with embeddings
7. Iterate and improve architecture so that performance on development data increases

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Thank You!
Any Questions?