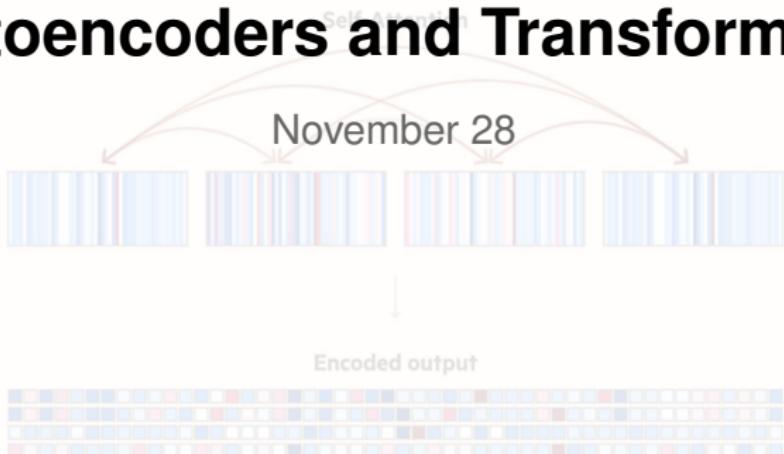


# Autoencoders and Transformers



# While you were feasting...

TECH

## OpenAI researchers warned board of AI breakthrough ahead of CEO ouster

PUBLISHED WED, NOV 22 2023 6:09 PM EST | UPDATED THU, NOV 23 2023 1:53 AM EST

 REUTERS

WATCH LIVE



Sam Altman, chief executive officer of OpenAI, during a fireside chat organized by Softbank Ventures Asia in Seoul, South Korea, on Friday, June 9, 2023.  
SeongJoon Cho | Bloomberg | Getty Images

# While you were feasting...

The maker of ChatGPT had made progress on Q\* (pronounced Q-Star), which some internally believe could be a breakthrough in the startup's search for superintelligence, also known as artificial general intelligence (AGI), one of the people told Reuters. OpenAI defines AGI as AI systems that are smarter than humans.

Given vast computing resources, the new model was able to solve certain mathematical problems, the person said on condition of anonymity because they were not authorized to speak on behalf of the company. Though only performing math on the level of grade-school students, acing such tests made researchers very optimistic about Q\*'s future success, the source said. Reuters could not independently verify the capabilities of Q\* claimed by the researchers.

# Welcome back!

- Quiz 5 before break
- Quiz 6 on December 7
- Assn 5 out; due Thursday
- Final exam: Friday Dec 15, 2pm in SSS 114
- Practice exams are posted
- Review sessions TBA

# Quiz 5

## Quiz Summary

Section Filter ▾

Student Analysis

Item Analysis

$\mu$  Average Score

$\circlearrowright$  High Score

$\circlearrowleft$  Low Score

$\sigma$  Standard Deviation

$\circlearrowright$  Average Time

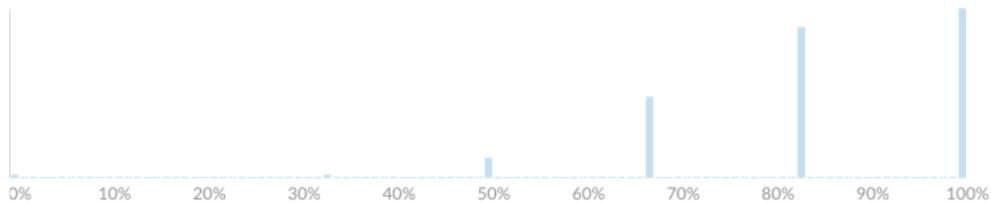
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14:17



# Requesting your help

- To make future iML classes run more smoothly, we are experimenting with a “ticketing” system
- Request: *For remainder of the semester, please make any requests (late assignments, regrades, etc.) by emailing sds265@yale.edu*
- This will allow us to test the system and process your requests more efficiently—thanks!

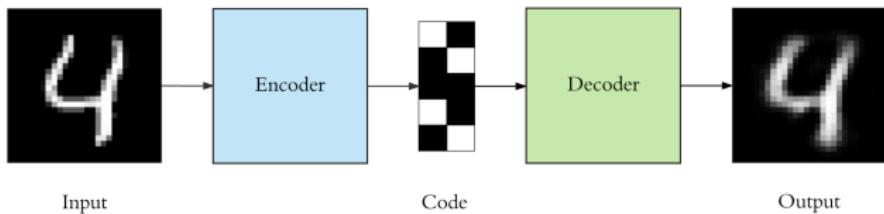
# For today

- Autoencoders
- Attention
- Transformers—high level

# Autoencoders

- Unsupervised learning methods
- Squeeze high dimensional data through a “bottleneck” of lower dimension
- Train to minimize reconstruction error

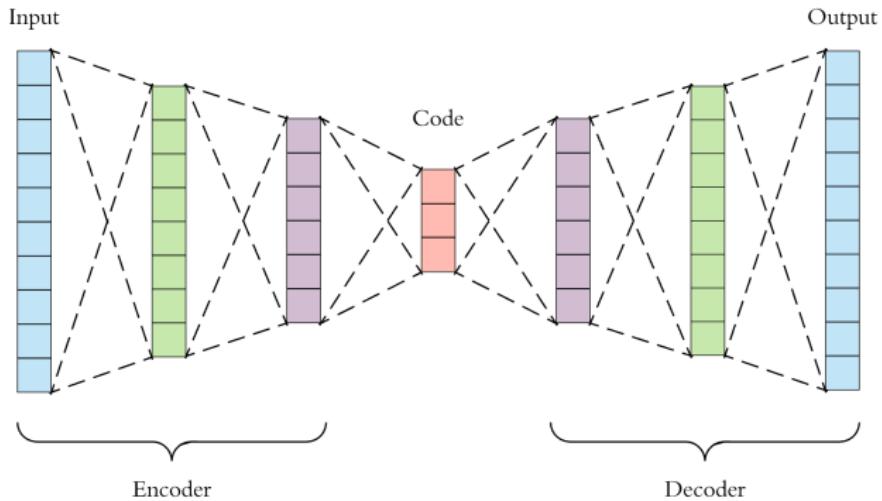
# Autoencoders



# Important aspects

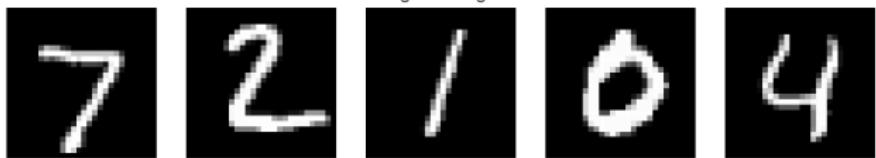
- Unsupervised: No labels used, discovers useful features of input
- Compression: Code reduces dimension of data
- Lossy: Input won't be reconstructed exactly
- Trained: The compression algorithm is learned for specific data

# Deep architecture



# MNIST data

Original Images



$$28 \times 28 = 784 = D$$

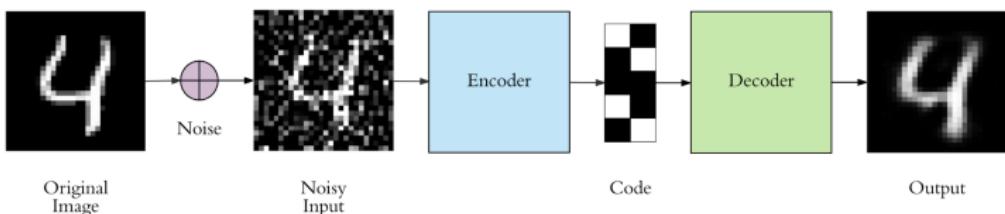
# Implementation using Keras

```
1  input_size = 784
2  hidden_size = 128
3  code_size = 32
4
5  input_img = Input(shape=(input_size,))
6  hidden_1 = Dense(hidden_size, activation='relu')(input_img)
7  code = Dense(code_size, activation='relu')(hidden_1)
8  hidden_2 = Dense(hidden_size, activation='relu')(code)
9  output_img = Dense(input_size, activation='sigmoid')(hidden_2)
10
11 autoencoder = Model(input_img, output_img)
12 autoencoder.compile(optimizer='adam', loss='binary_crossentropy')
13 autoencoder.fit(x_train, x_train, epochs=5)
```

# Adam optimizer

- Variant of stochastic gradient descent where separate learning rate (step size) is maintained for each network weight (parameter)
- Each step size adapted as learning progresses based on moments of the derivatives

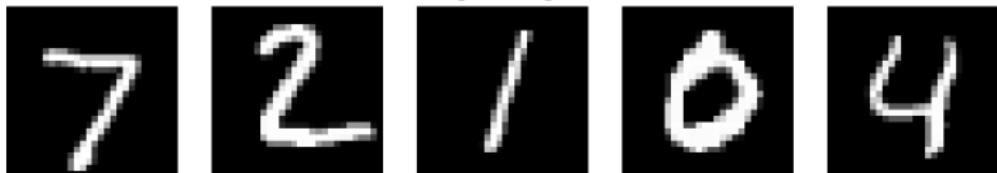
# Variant: Denoising autoencoder



- Feed in noisy data
- Train to match to denoised data

# Example result on MNIST

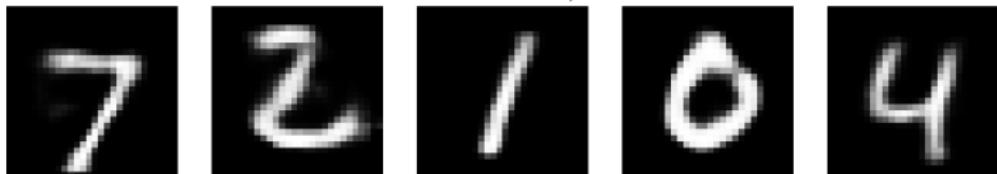
Original Images



Noisy Input



Autoencoder Output





deep-nets.ipynb

File Edit View Insert Runtime Tools Help Cannot save changes

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## ▼ Autoencoders

{x}

This code includes implementations of various simple autoencoders using the Keras front end to TensorFlow. We'll run all of the code on the MNIST data to gain a basic understanding of what everything is doing. You'll then run this on the Fashion MNIST data.



The starter code for this demo is from <https://github.com/ardendertat/Applied-Deep-Learning-with-Keras>. For Keras documentation, see <https://keras.io>.

✓ 7s

```
from __future__ import print_function
%matplotlib inline
%config InlineBackend.figure_format = 'retina'
import matplotlib.pyplot as plt
import pandas as pd
import numpy as np
import warnings
```



# Summary of Autoencoders

- Autoencoders compress the input and then reconstruct it
- Bottleneck forces extraction of useful features
- Will overfit and “memorize” the data
- Overfitting mitigated by denoising autoencoders

## Next: High-level overview of transformers

- We'll treat transformers at a high level
- Key notion: Attention
- Main intuition illustrated with word embeddings

Artificial Intelligence

# Generative AI exists because of the transformer

This is how it works

By Visual Storytelling Team and Madhumita Murgia in London SEPTEMBER 12 2023

# Starting point: Word embeddings

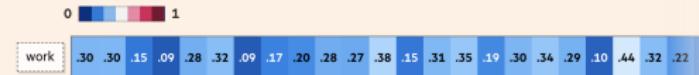
Eventually, we end up with a huge set of the words found alongside work in the training data, as well as those that weren't found near it.

work	office
work	has
work	zebra
work	polka
work	roof
work	effort
work	and
work	at
work	downtown
work	hard
work	a
work	to
work	dove
work	in
work	atmosphere
work	his

# Starting point: Word embeddings

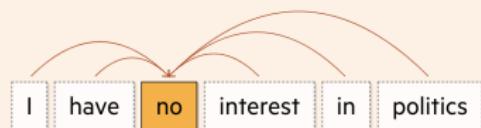
As the model **processes** this set of words, it produces a vector — or list of values — and adjusts it based on each word's proximity to **work** in the training data. This vector is known as a word embedding.

work	office
work	has
work	zebra
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work	and
work	at
work	downtown
work	hard
work	a
work	to
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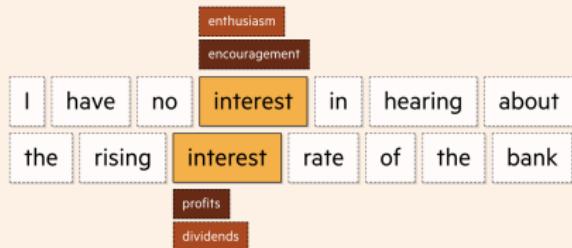
# Introducing context: Attention

Self-attention looks at each **token** in a body of text and decides which others are most important to understanding its meaning.



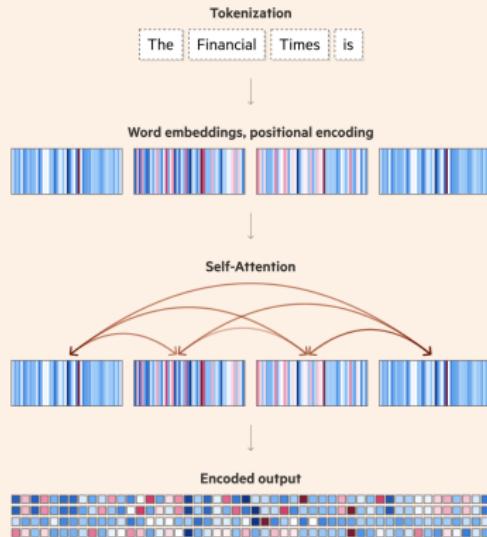
# Introducing context: Attention

This functionality is crucial for advanced text generation. Without it, words that can be interchangeable in some contexts but not others can be used incorrectly.



# Building up: Encoding Layers

After tokenising and encoding a prompt, we're left with a block of data representing our input as the machine understands it, including meanings, positions and relationships between words.



# Building up: Encoding Layers

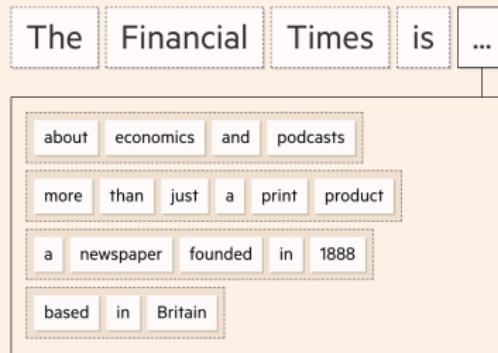
At its simplest, the model's aim is now to predict the next word in a sequence and do this repeatedly until the output is complete.



# Making predictions: Beam search

Transformers use a number of approaches to address this problem and enhance the quality of their output. One example is called **beam search**.

Rather than focusing only on the next word in a sequence, it looks at the probability of a larger set of tokens as a whole.



# Attention/Alignment

We'll next illustrate attention in a “sequence-to-sequence” task, like translating a sentence from French to English.

- Each source/targe word is associated with an encoder/decoder state—a vector of neurons.
- On each step of decoding, directly connect to the encoder, and focus on a particular part of the source sequence

# Attention/Alignment

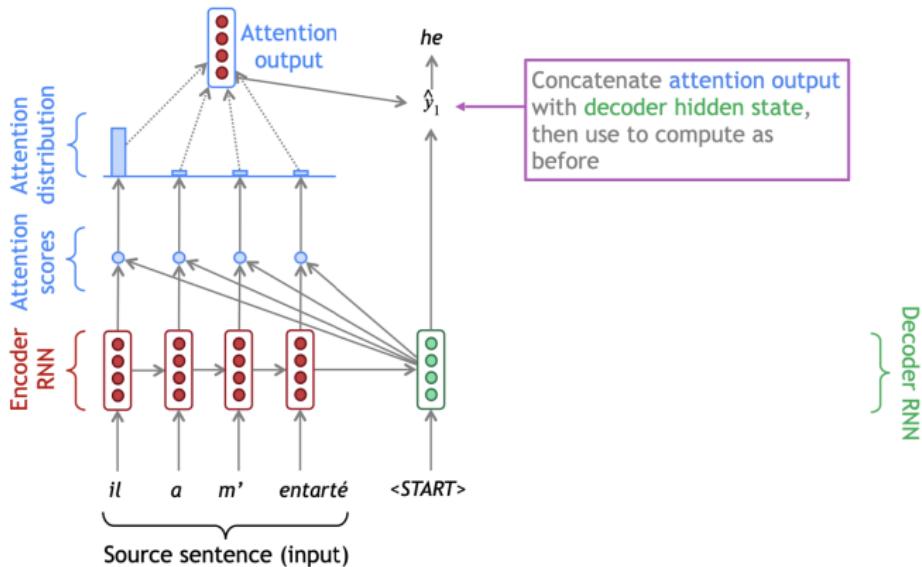


figure source: <http://web.stanford.edu/class/cs224n/slides/cs224n-2020-lecture08-nmt.pdf>

# Attention/Alignment

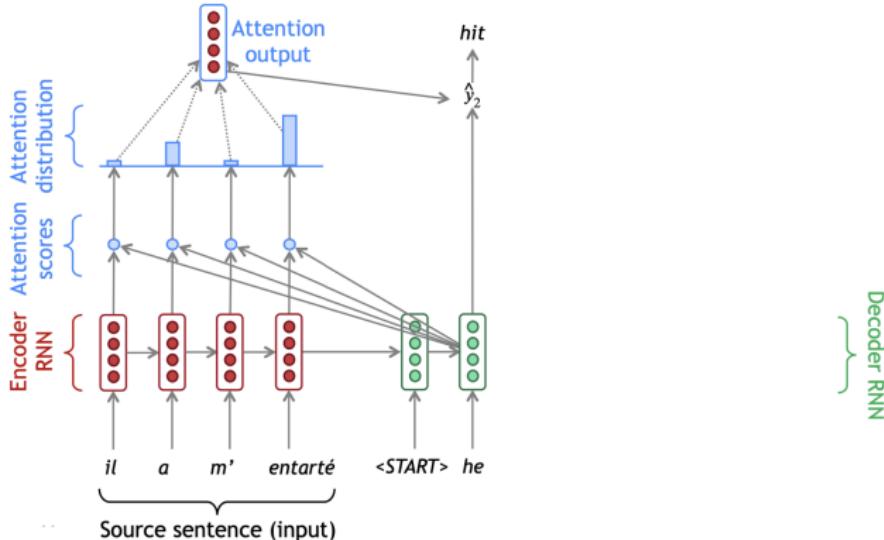


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# Attention/Alignment

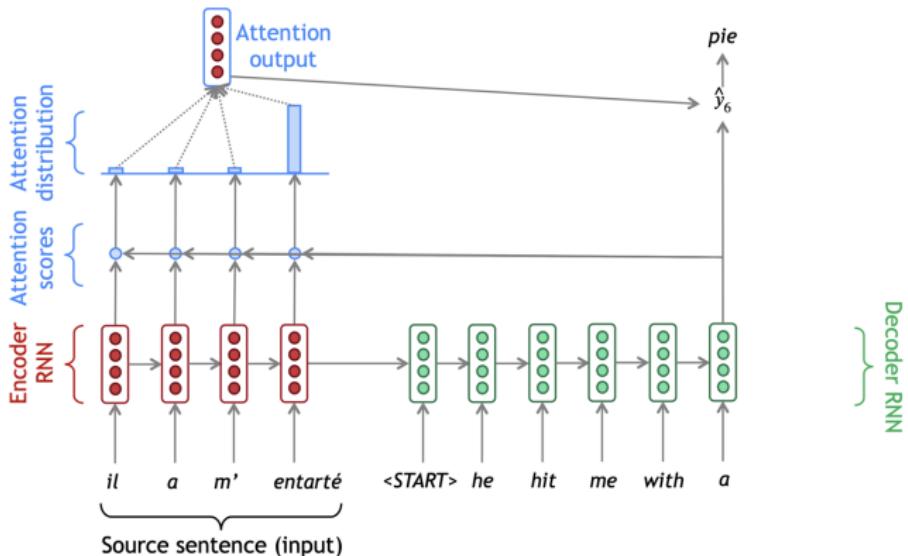
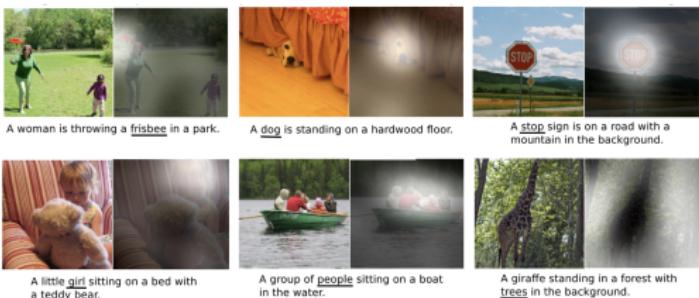
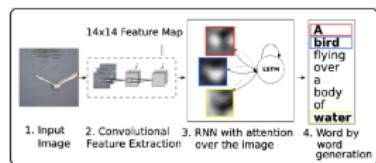


figure source: <http://web.stanford.edu/class/cs224n/slides/cs224n-2020-lecture08-nmt.pdf>

# Attention/Alignment

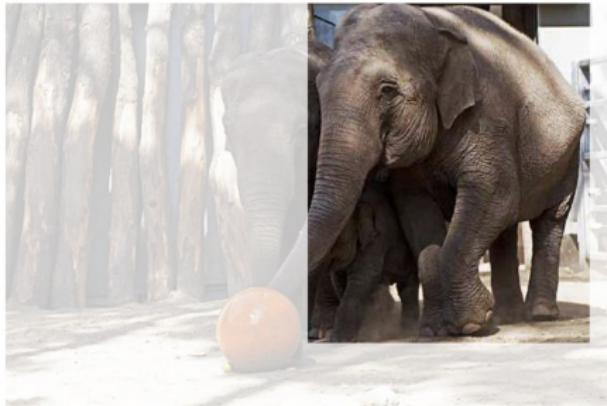
Attention can also be used for other generative models



\* "Show, attend and tell: neural image caption generation with visual attention", Xu et al. 2016, <https://arxiv.org/pdf/1502.03044.pdf>







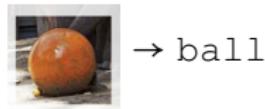




The two elephants played with an orange ball



The two elephants played with an orange ball



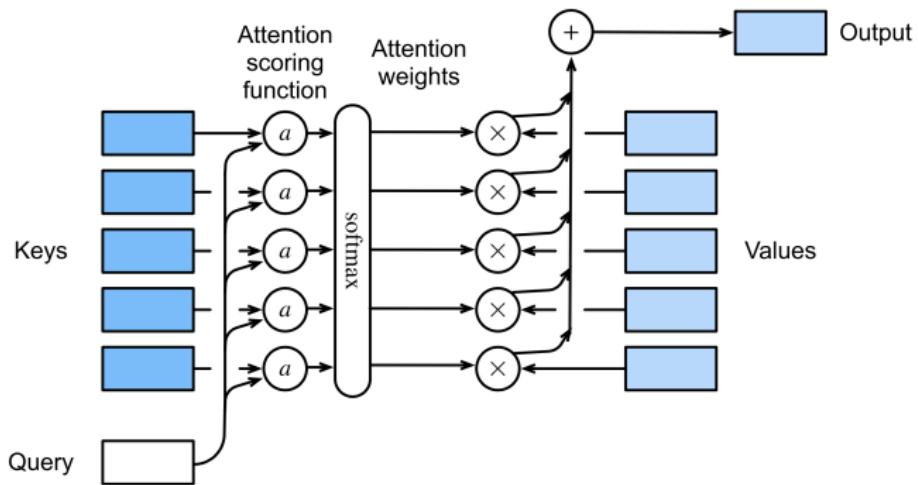
# Attention in terms of query/key/values

Basic idea behind attention mechanisms:

- We have a set of  $m$  feature vectors or values  $V \in \mathbb{R}^{m \times v}$
- The model dynamically chooses which to use
- based on how similar a query vector  $q \in \mathbb{R}^q$  is to a set of  $m$  keys  $K \in \mathbb{R}^{m \times k}$ .
- If  $q$  is most similar to key  $i$ , then we use value (feature)  $v_i$ .

# Attention in terms of query/key/values

Basic idea behind attention mechanisms:



# Attention in terms of query/key/values

Basic idea behind attention mechanisms:

$$\text{Attn}(q, \{(k_1, v_1), \dots (k_m, v_m)\}) = \sum_{i=1}^m w_i(q, k_{1:m}) v_i$$

where weights  $w_i$  are softmax of attention scores  $a(q, k)$ :

$$w_i(q, k_{1:m}) = \frac{\exp(a(q, k_i))}{\sum_{j=1}^m \exp(a(q, k_j))}$$

# Dot product attention

Attention scores are computed as

$$a(q, k_i) = (W_1 q)^T (W_2 k_i)$$

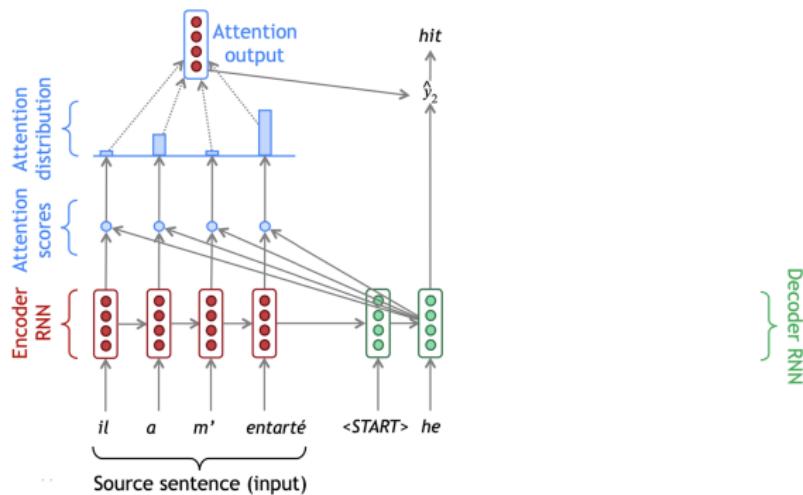
and then the attention weights are the softmax:

$$\text{Attn}(q, k_{1:m}, v_{1:m}) = \text{Softmax}(a(q, k)) v$$

*The matrices  $W_1$  and  $W_2$  allow comparison of query and keys from different “languages”—French and English or images and words*

# Retour d'entarté

In the *entarté* example, the keys and values are the red state vectors, the queries are the green state vectors



# Transformers

The current state-of-the-art is based on *transfomers*

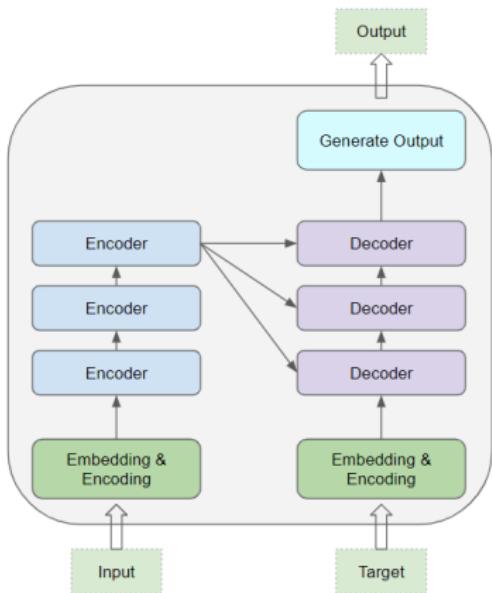
- Attention is the key ingredient
- Rather than processing sequences word-by-word, transformers handle larger chunks of text at once
- The separation between words matters less

# Combining attention vectors



- Different attention vectors are stacked up on top of each other
- Words “hungry” and “sweet” are predicted using all of them

# Transformer architecture



# Summary

- Attention is a type of alignment between related words
- Attention allows dynamic construction of word contexts, useful for predicting the next word
- Attention is computed using inner products, after mapping query and key to a common space
- Transformers process all words together, using layers of encoders and decoders, each with an attention component