

# Transformers and embeddings

Dirk Wulff & Zak Hussain



**MAX PLANCK INSTITUTE**  
FOR HUMAN DEVELOPMENT





**John Rupert Firth**  
Linguist  
1890-1960





**“You’ll know  
a word by  
the company  
that it  
keeps!”**

**John Rupert Firth**  
Linguist  
1890-1960



# Word embedding

## Latent semantic analysis

		Contexts											
Word	this region of the galaxy	Context 1	1										
			1										
			1										
			1										
			1										

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A wide slit opened at eye-level, and I could see the stars. The \_Prometheus\_ was orbiting in the region of Alpha in Aquarius and I tried in vain to orient myself; a glittering dust filled my porthole. I could not recognize a single constellation; in this region of the galaxy the sky was unfamiliar to me. I waited for the moment when I would pass near the first distinct star, but I was unable to isolate any one of them. Their brightness was fading; they receded, merging into a vague, purplish glimmer, the sole indication of the distance I had already travelled. My body rigid, sealed in its pneumatic envelope, I was knifing through space with the impression of standing still in the void, my only distraction the steadily mounting heat.

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## Latent semantic analysis

		Contexts											
Word		Context 1	Context 2										
	this	1											
	region	1	1										
	of	1	1										
	the	1	2										
	galaxy	1	1										

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		Contexts										
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	region	1										
	of	1	1									
	the	1	1	1								
	galaxy	1	2	2								
	sky	1	1	1								
				1								

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		Contexts									
Word		Context 1	Context 2	Context 3	...	Context m					
	this	1									
	region	1	1								
	of	1	1	1		1					
	the	1	2	2		1					
	galaxy	1	1	1							
	sky			1							
	...										
	image					1					
	dial					1					
shivered						1					

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	region	1	1								
	of	1	1	1		1				1	
	the	1	2	2		1					
	galaxy	1	1	1					1		
	sky			1				2			1
	...				1						
	image					1					3
dial						1			1		
shivered						1				1	
...											1
Word <i>N</i>									1		

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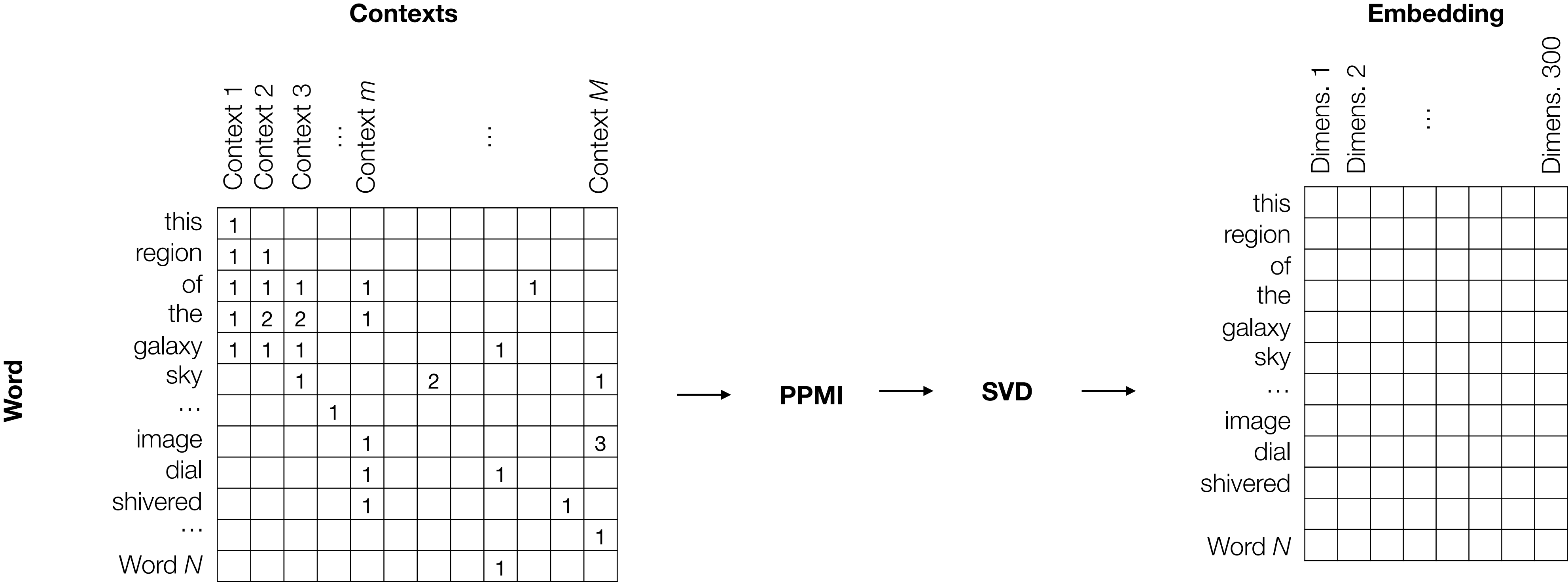
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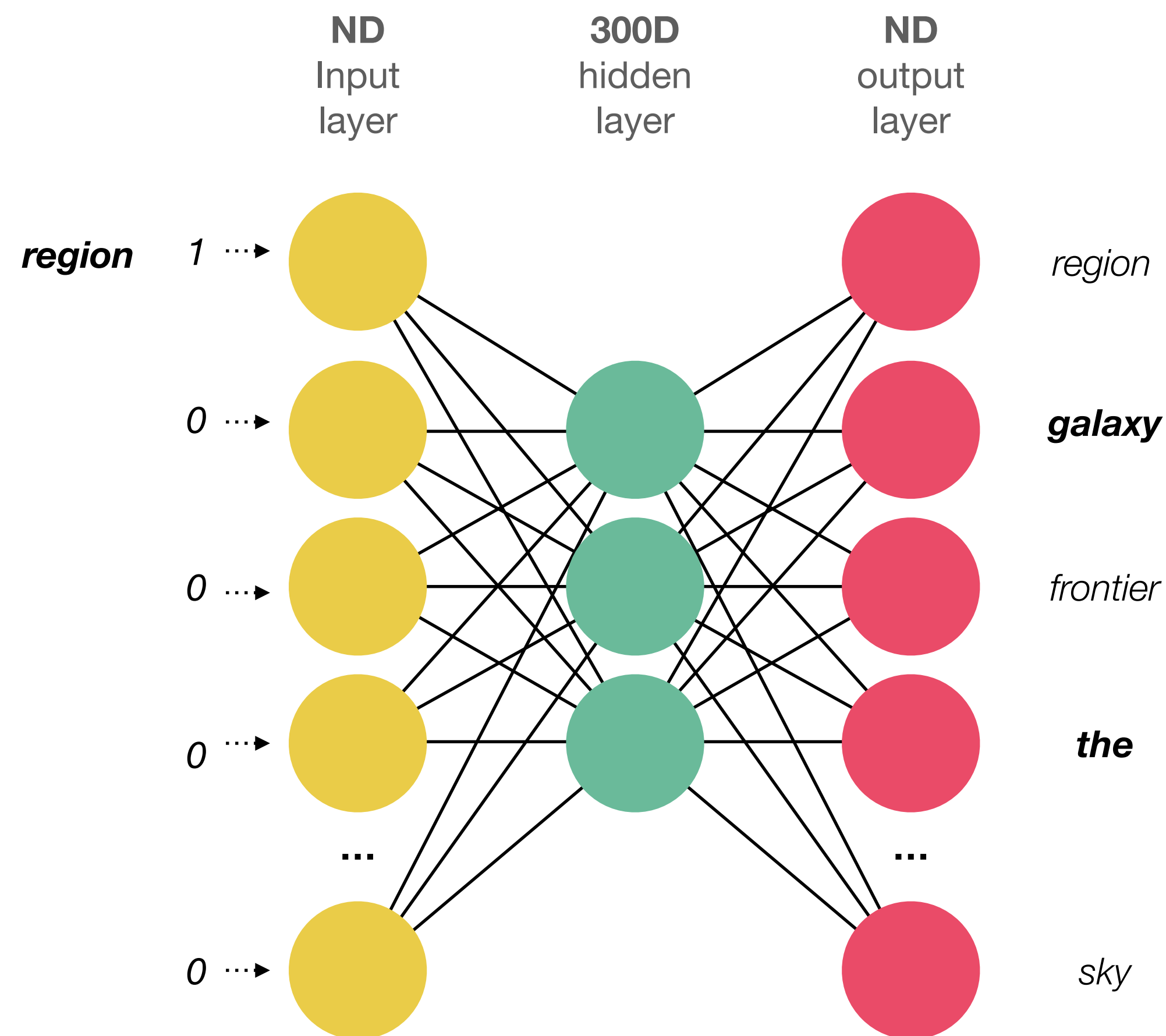
Latent semantic analysis





# Word embedding

word2vec



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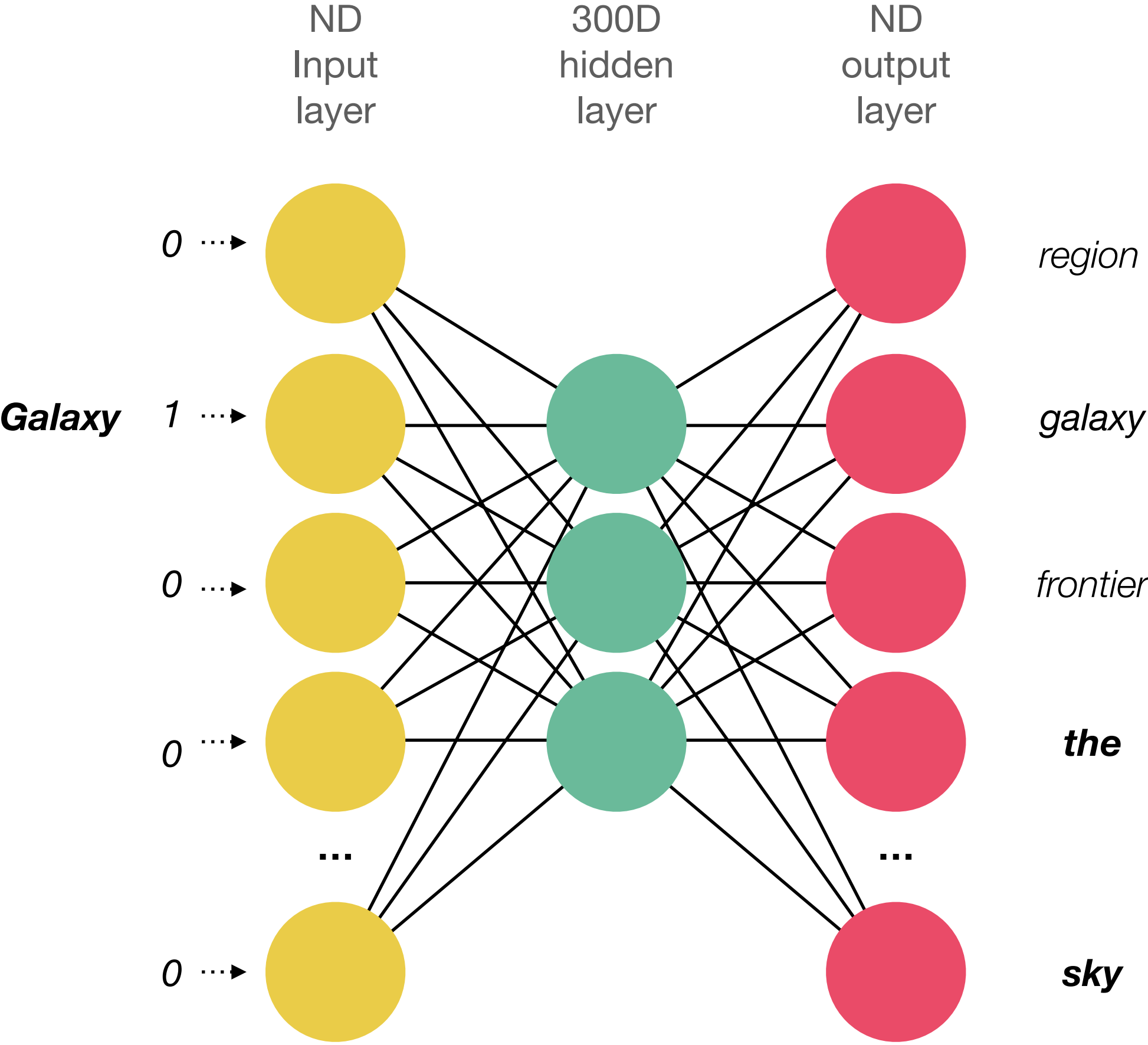
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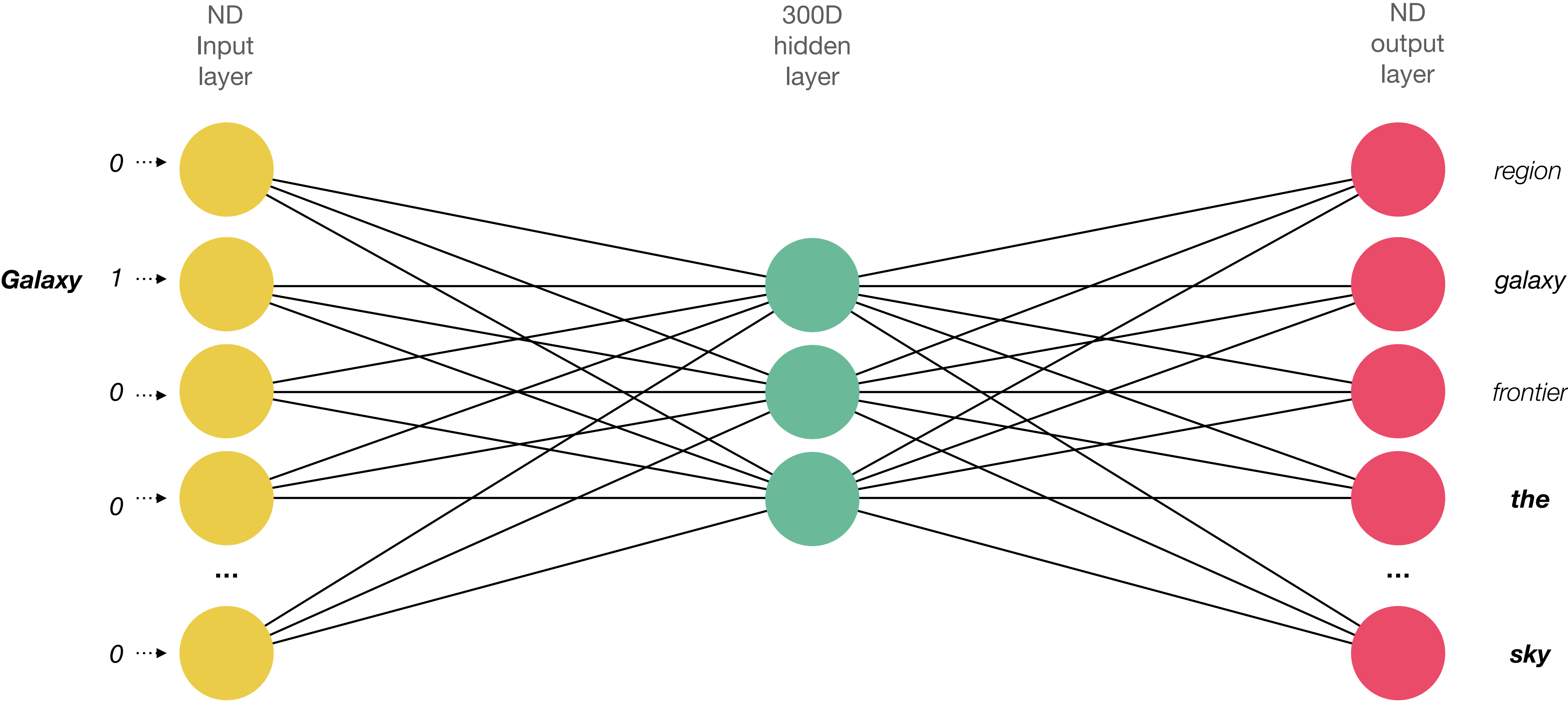
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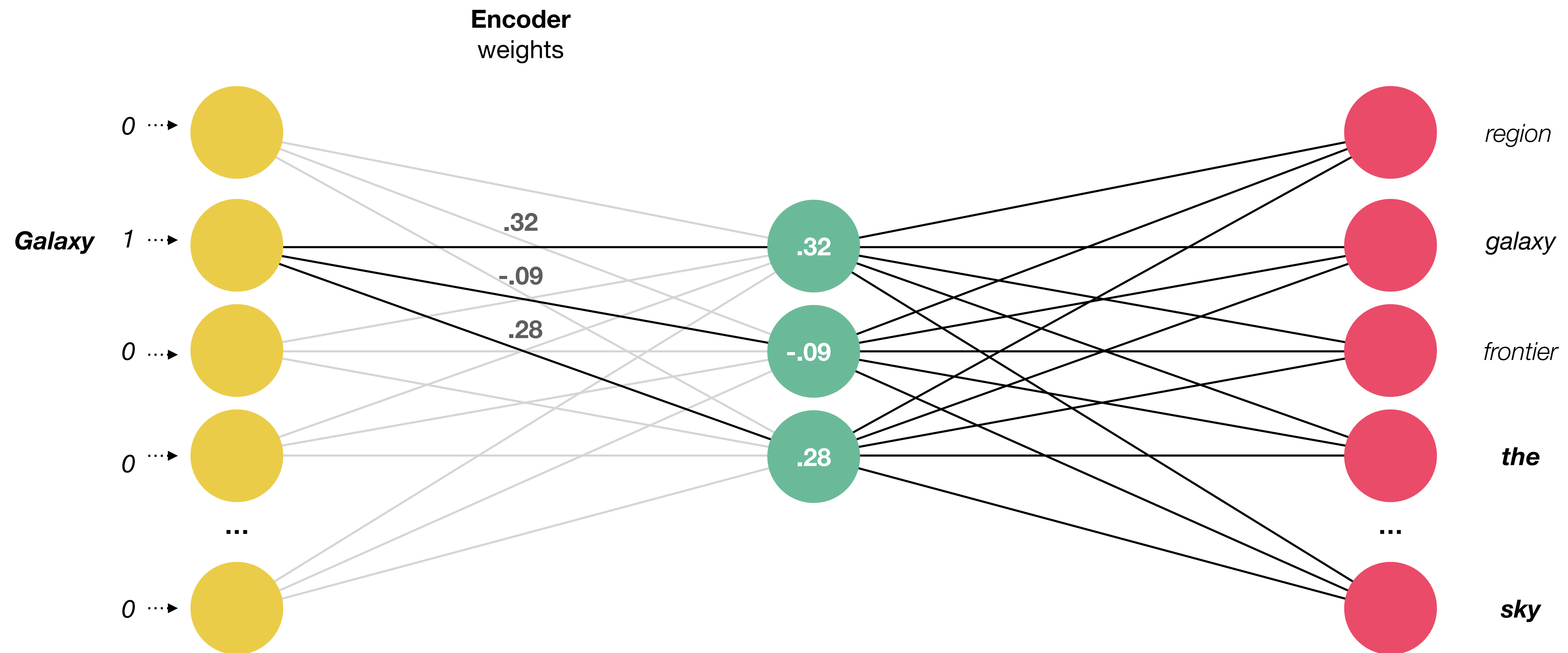
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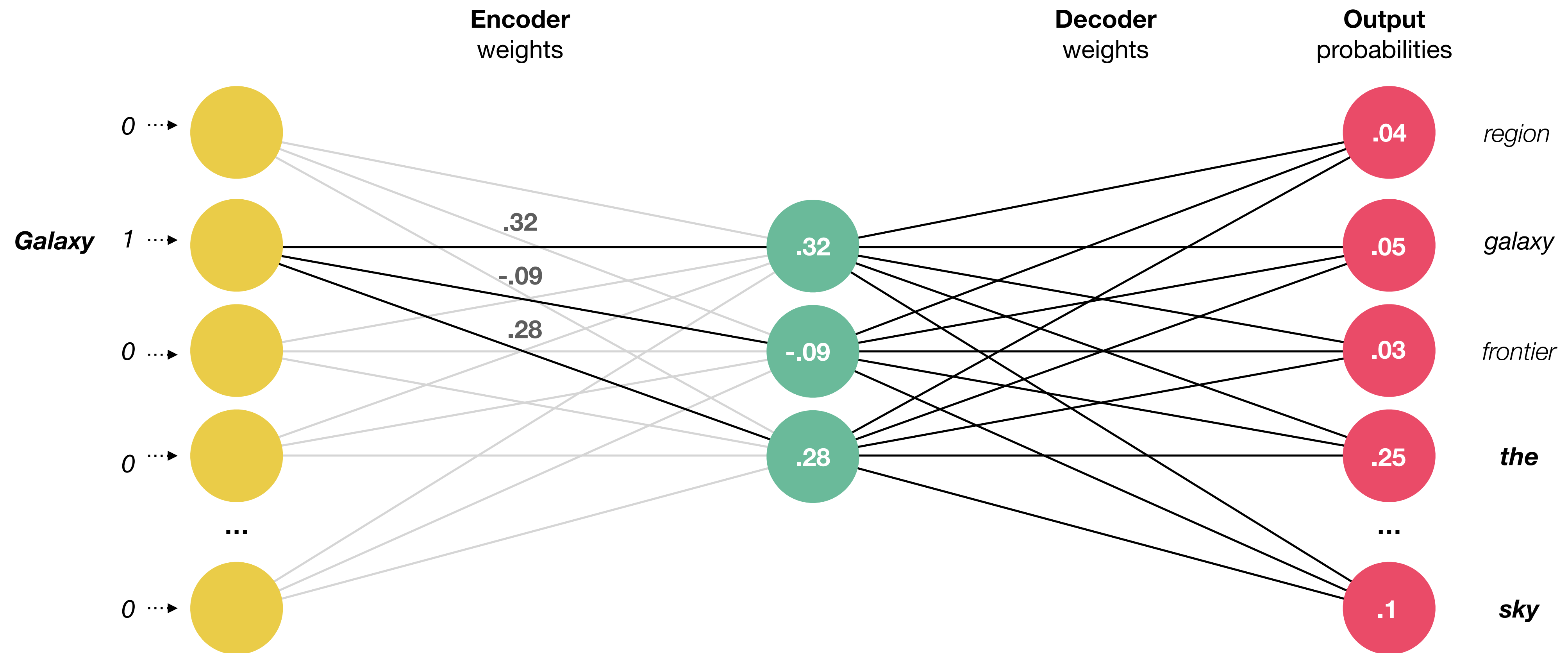
“A good language model encodes words with similar output similarly”





# Word embedding

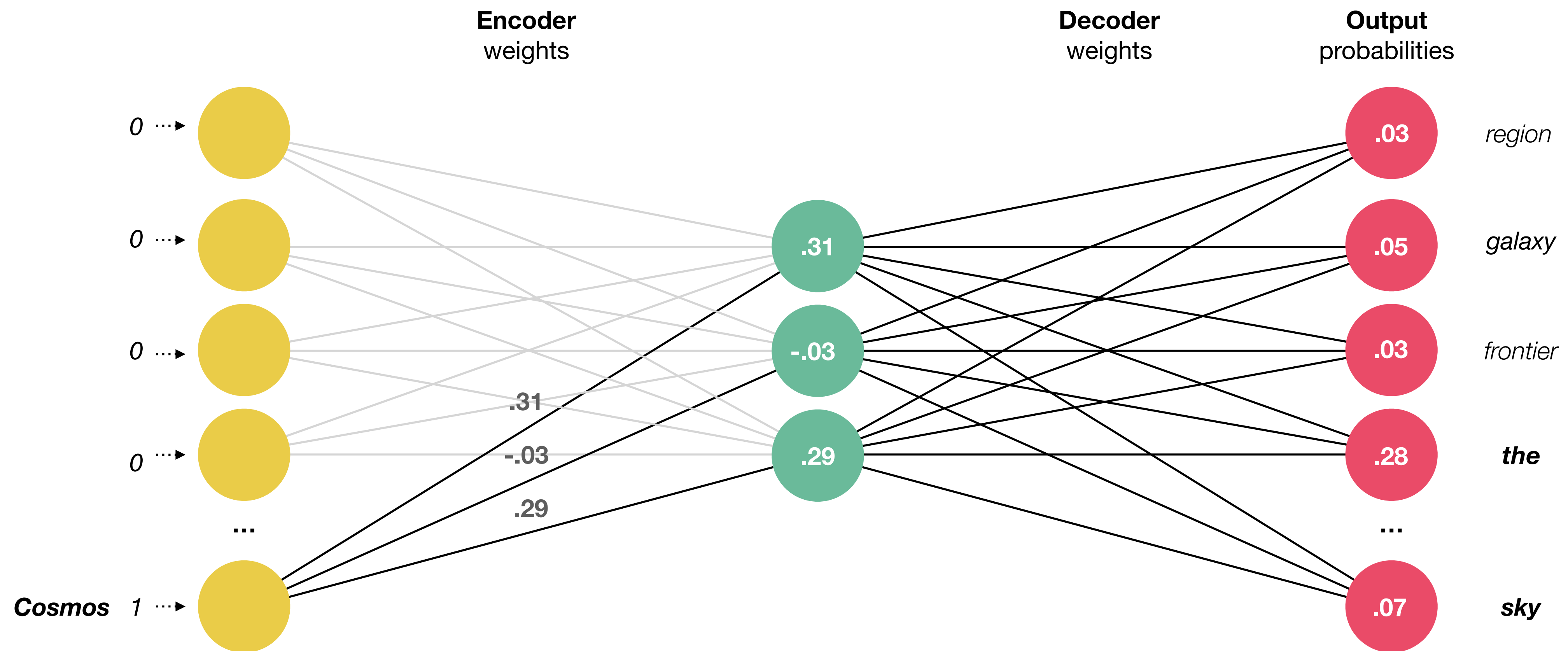
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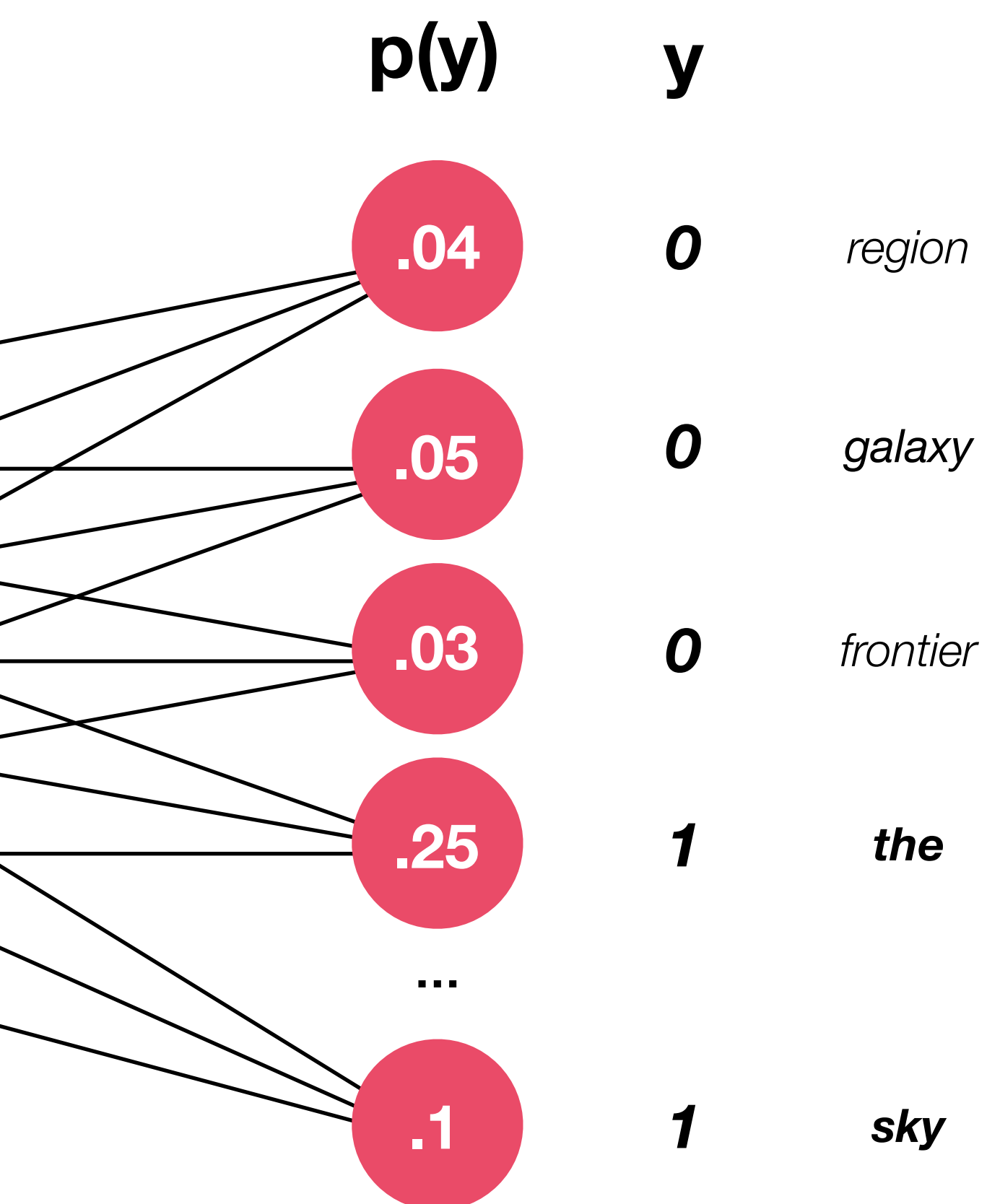
# Word embedding

“A good language model encodes words with similar context similarly”



# Error signal

## and gradient descent



Sum over context **contexts**    Sum over context **words**    **Criterion**  
 0 if word is absent  
 1 if word is present    **Model prediction**  
 Softmax probability

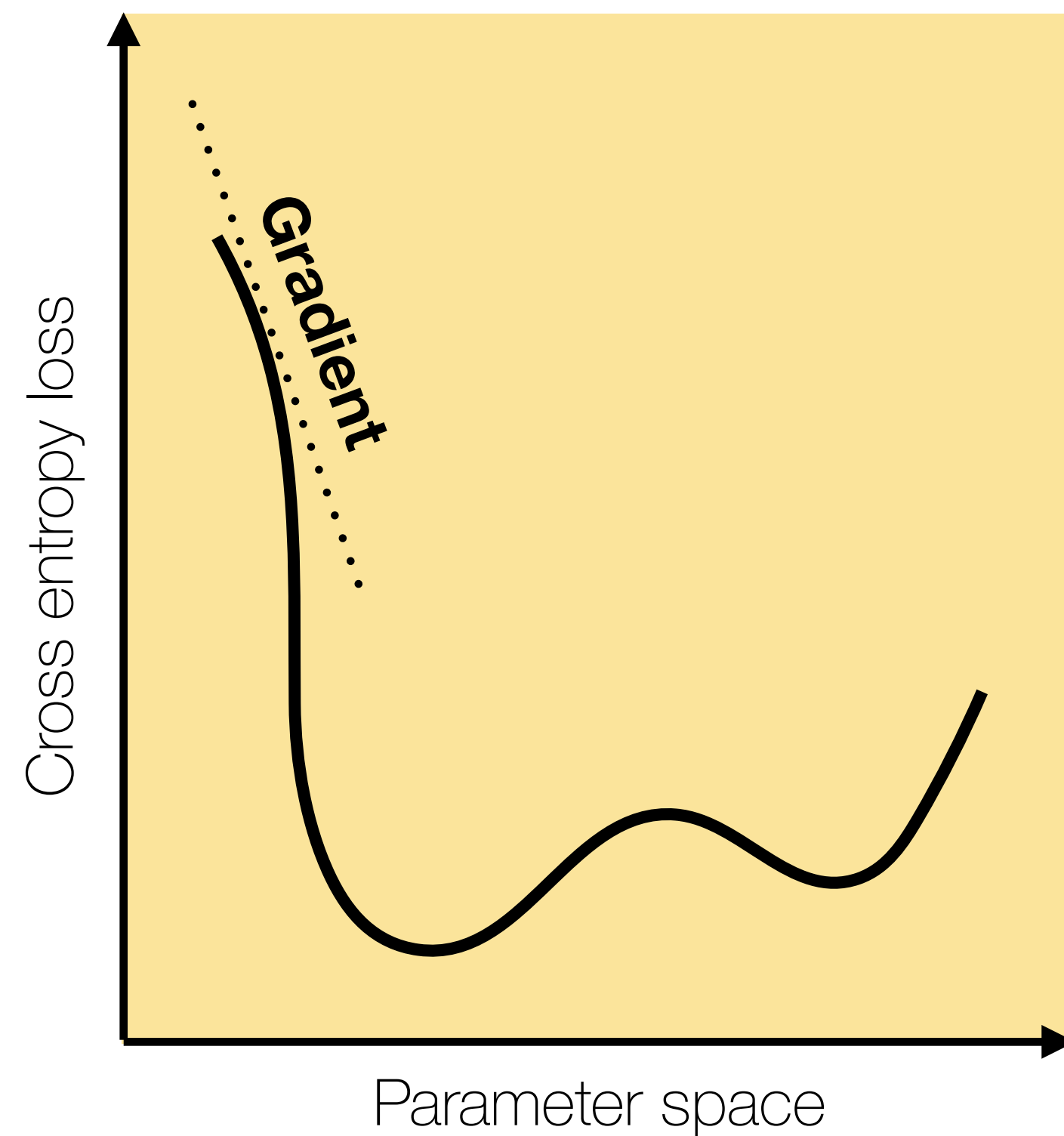
$$-\sum_i \sum_j y_{ij} \log p(y_{ij})$$

**Cross entropy loss**



# Error signal

and gradient descent



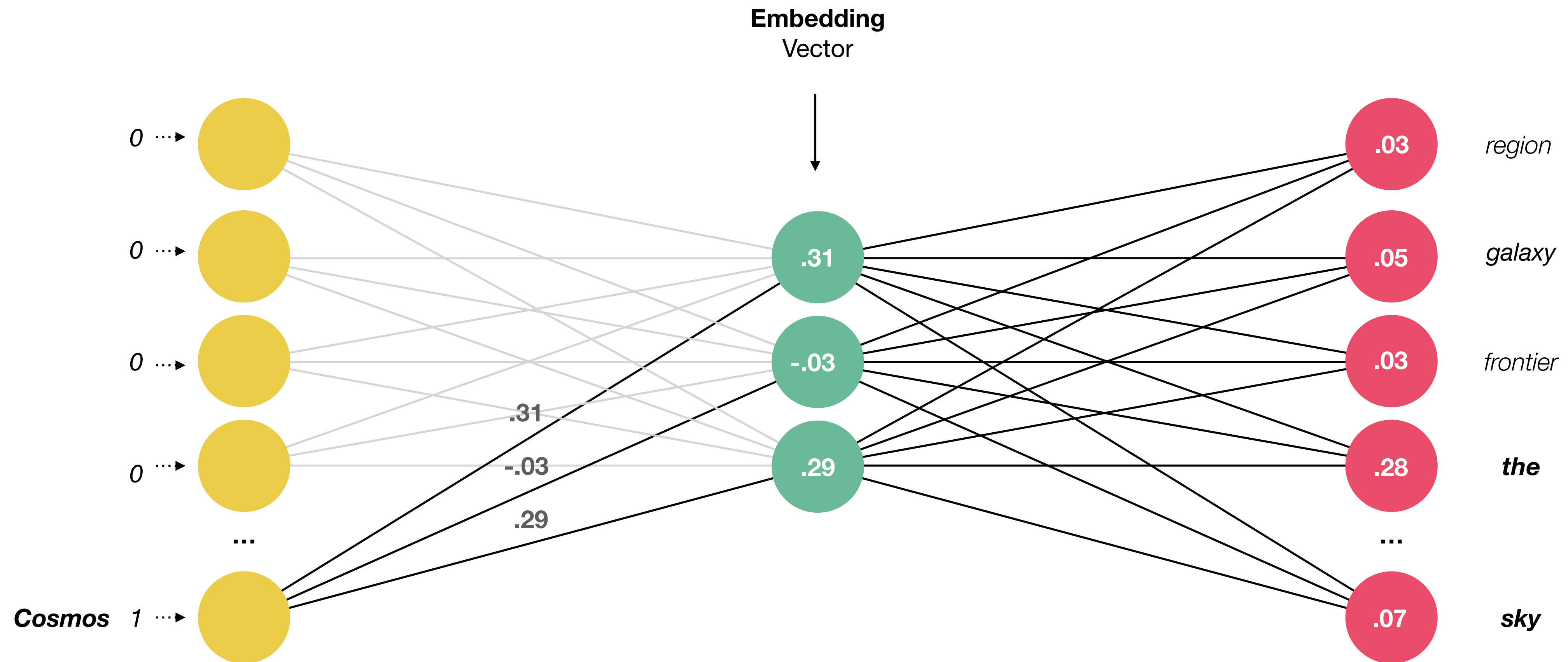
Sum over context <b>contexts</b>	Sum over context <b>words</b>	<b>Criterion</b> 0 if word is absent 1 if word is present	<b>Model prediction</b> Softmax probability
--	-------------------------------------	---	---

$$-\sum_i \sum_j y_{ij} \log p(y_{ij})$$

Cross entropy loss

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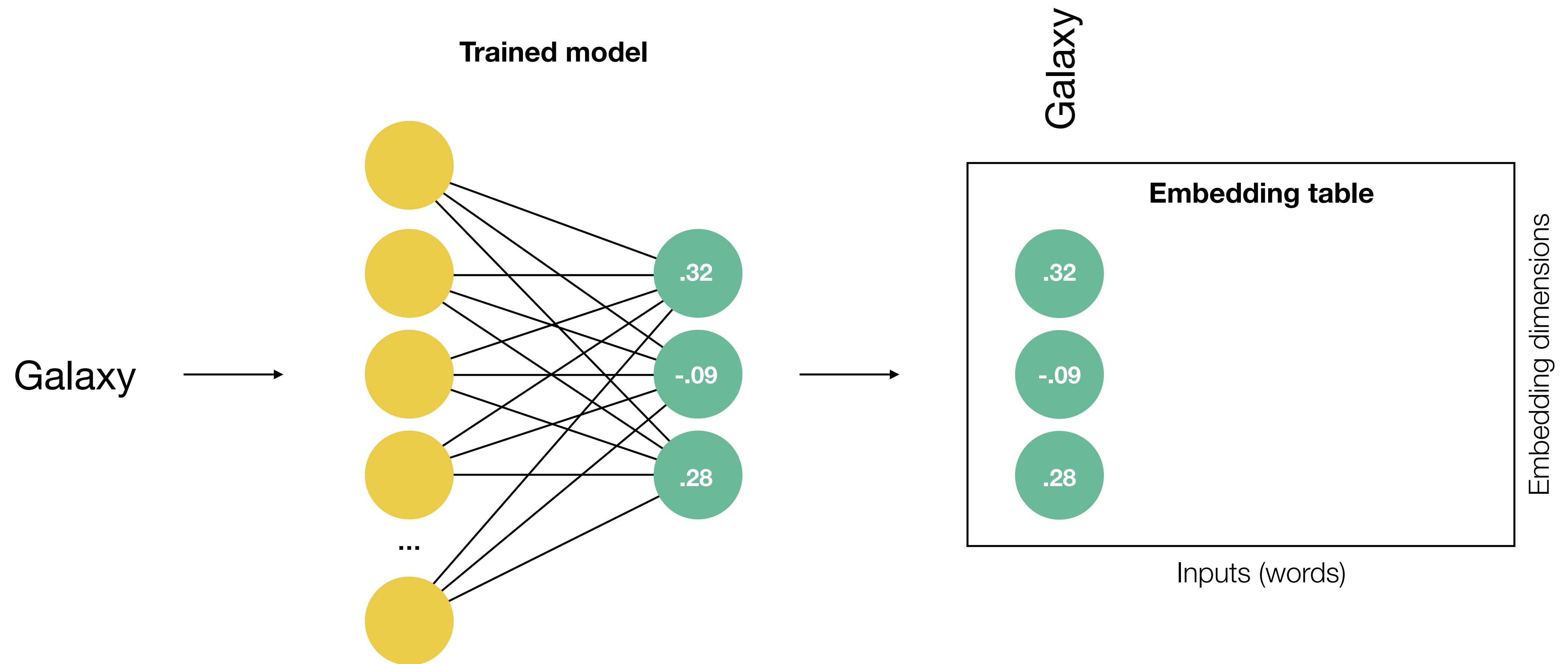
Embeddings = hidden activations (typically right before the output)





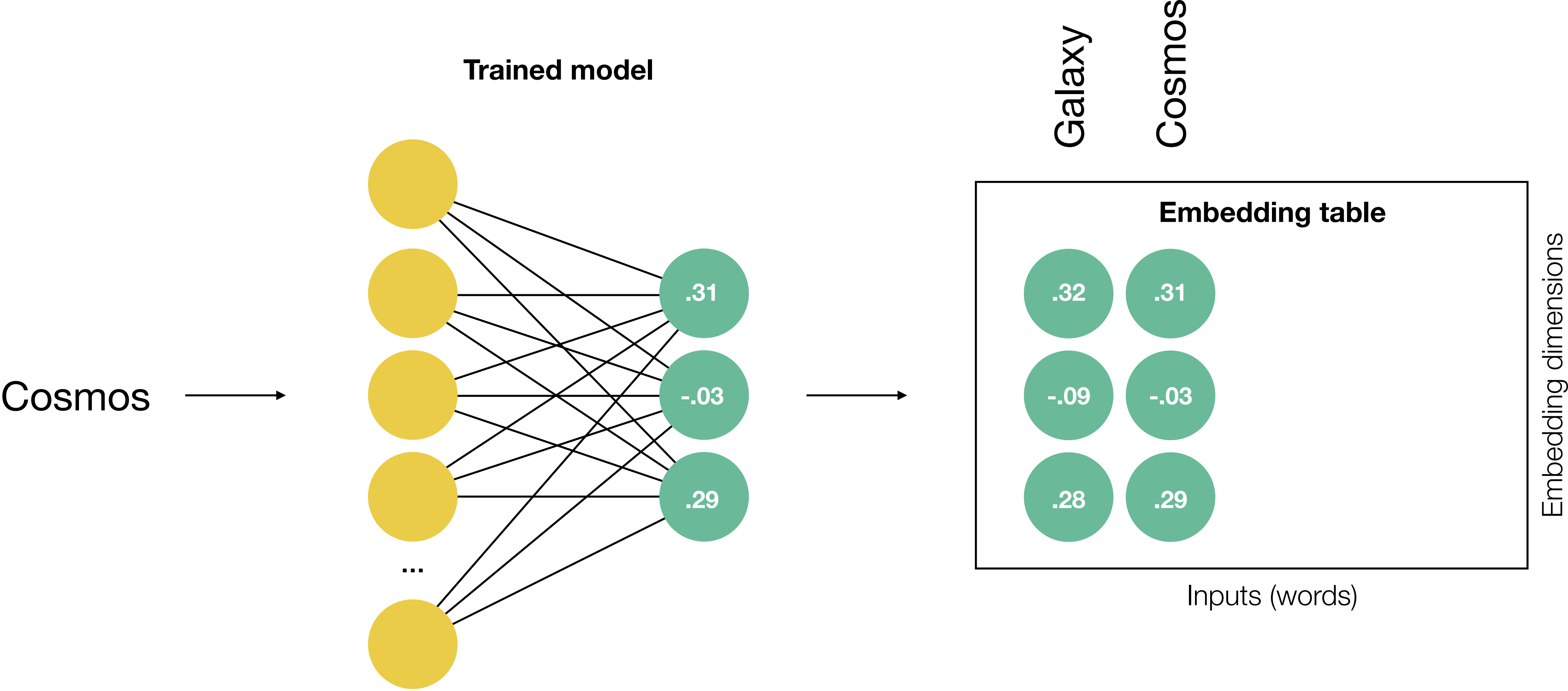
# Generating embeddings

or recording hidden activations



# Generating embeddings

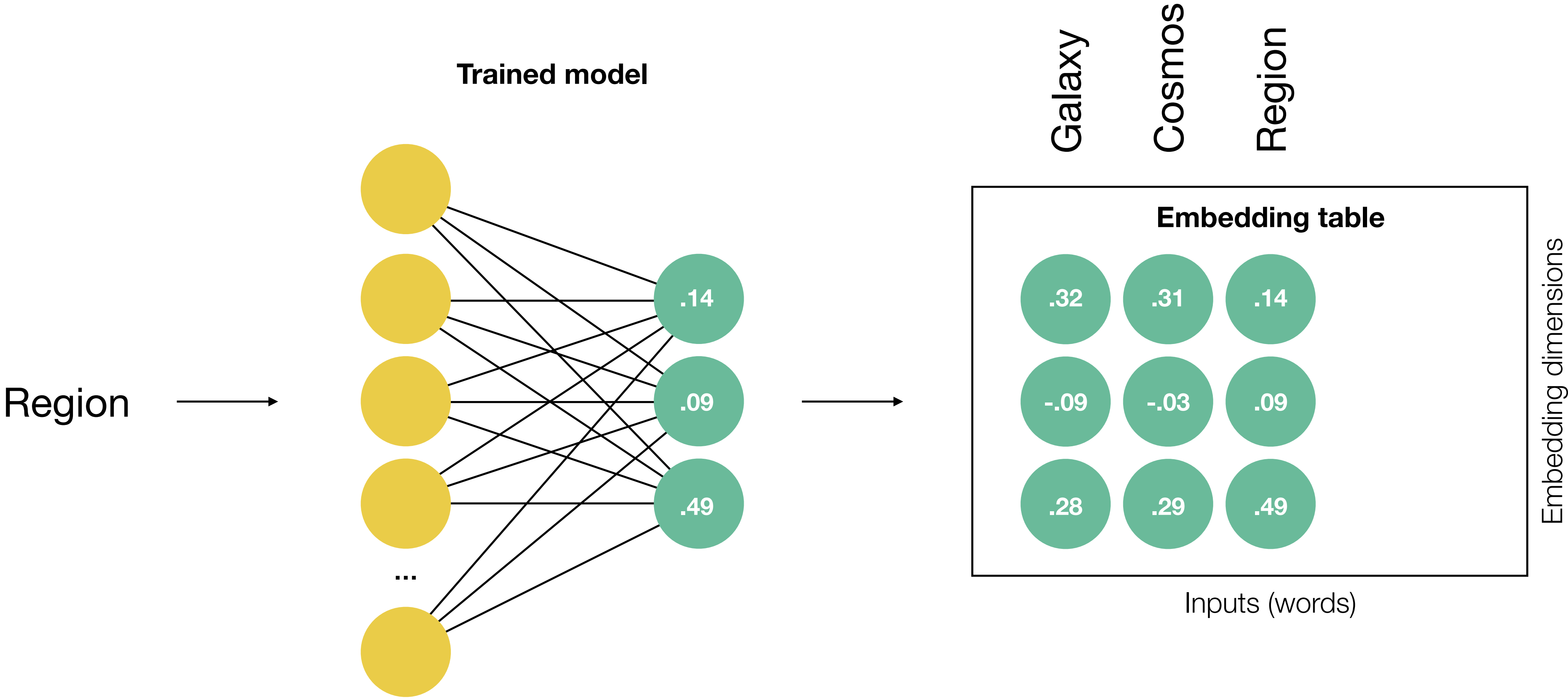
or recording hidden activations





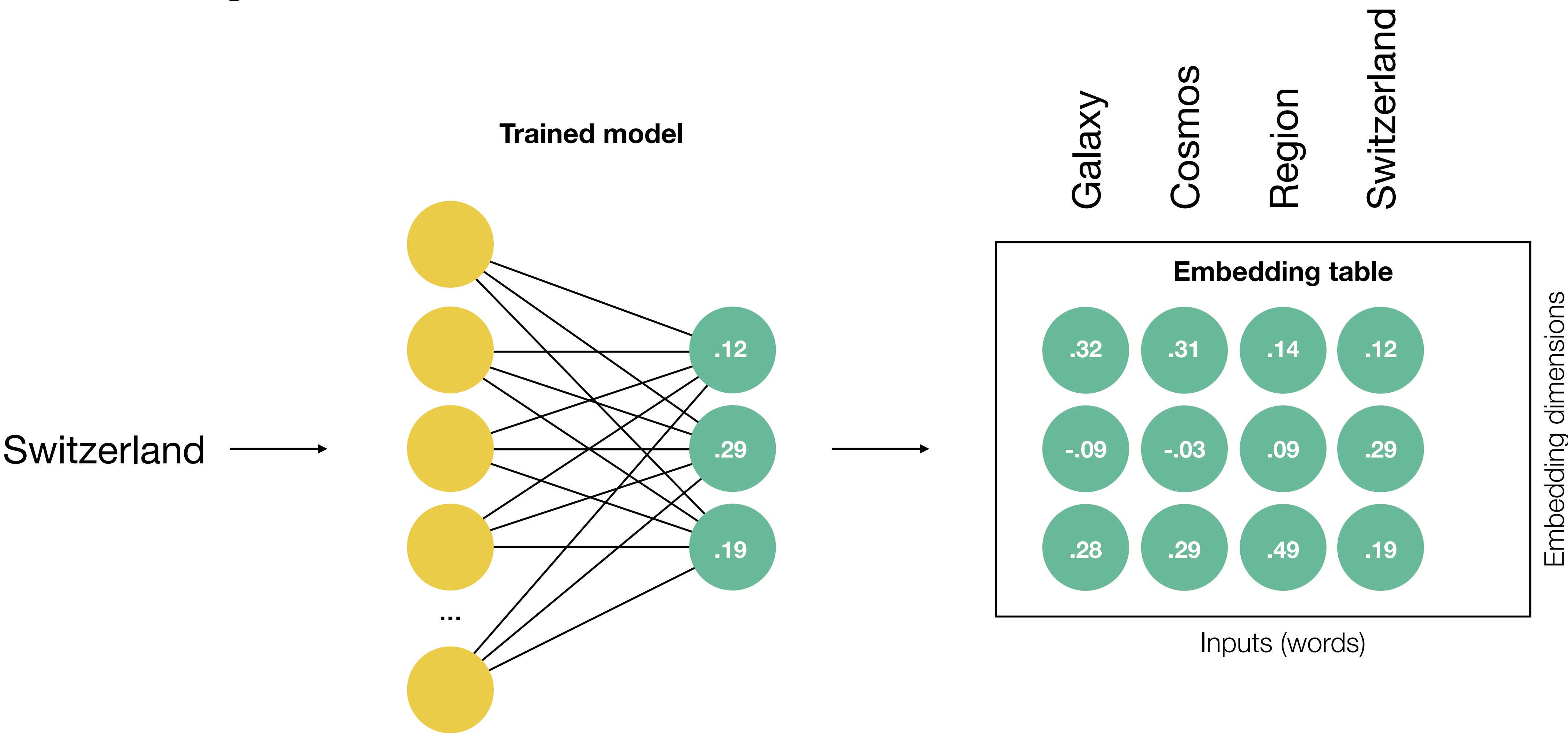
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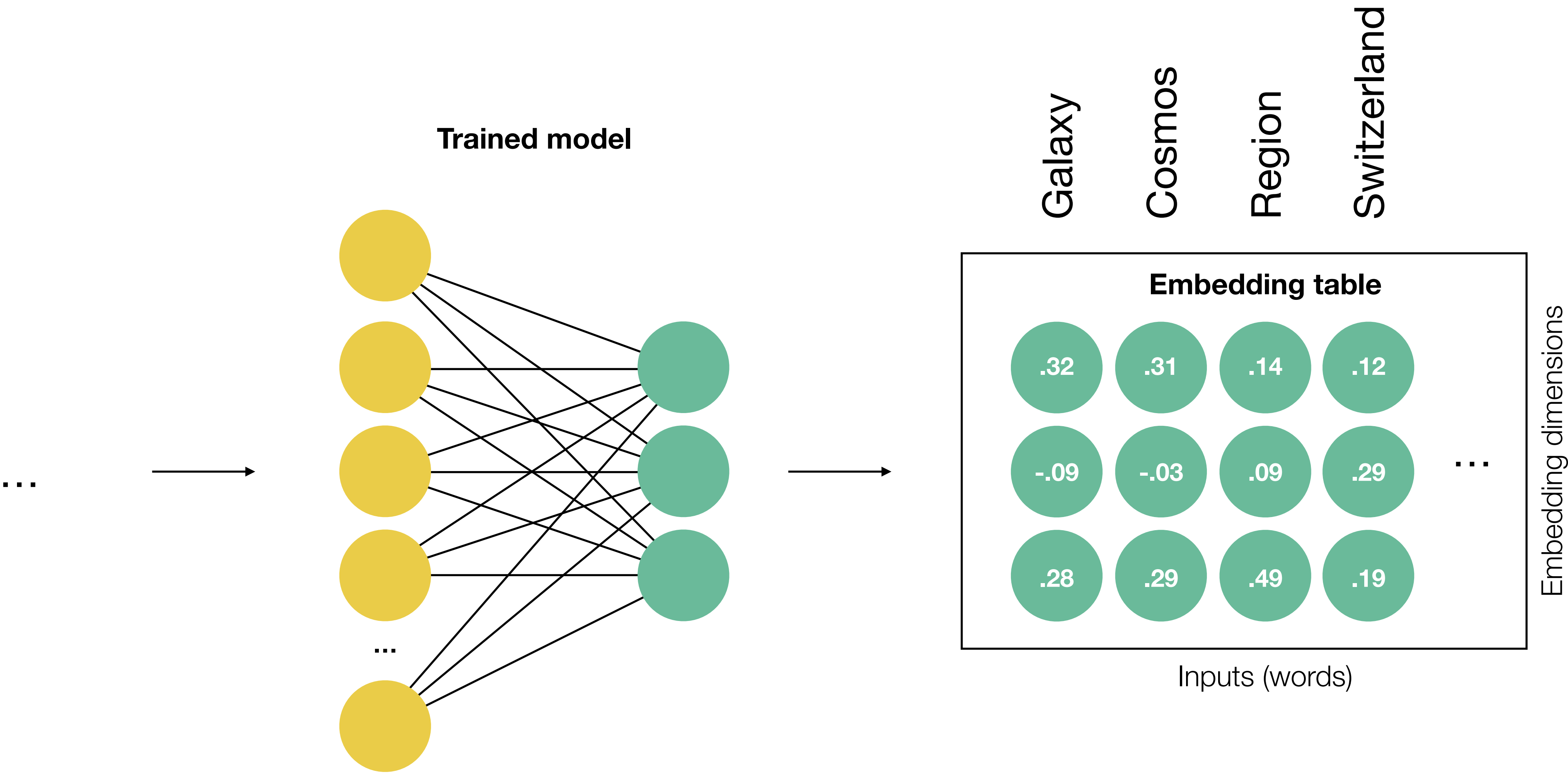
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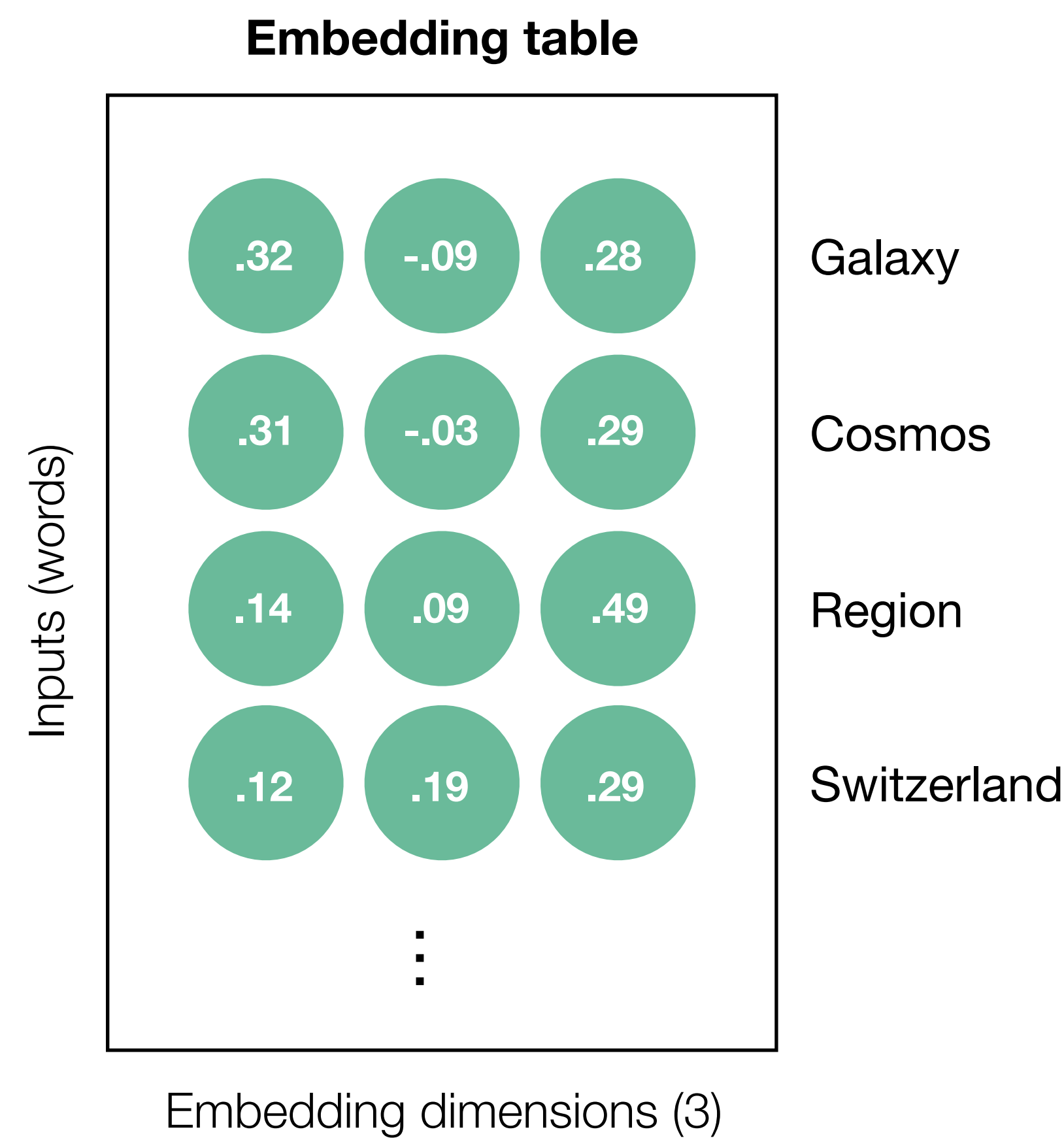
# Generating embeddings

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# Comparing embeddings

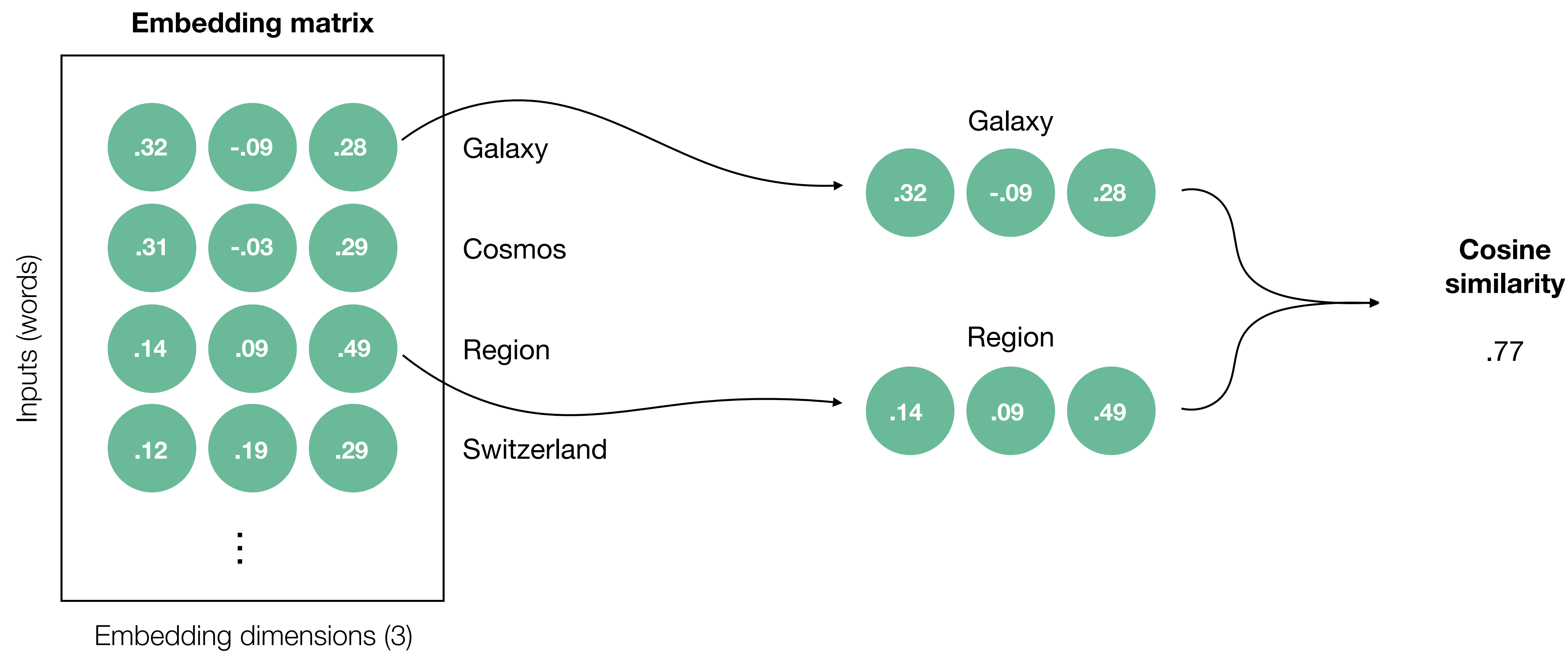
Using cosine similarity





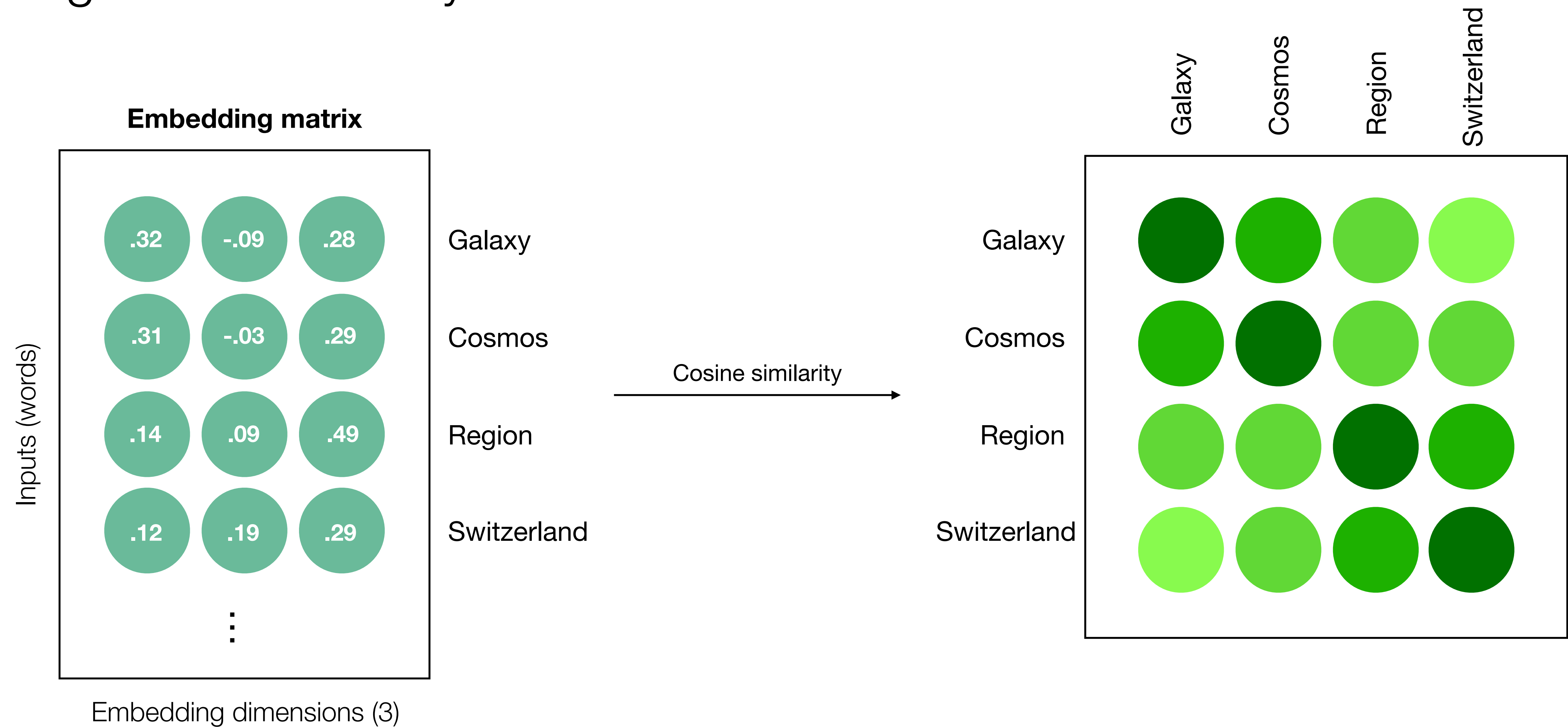
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# Intro to transformers and embedding 2

Dirk Wulff

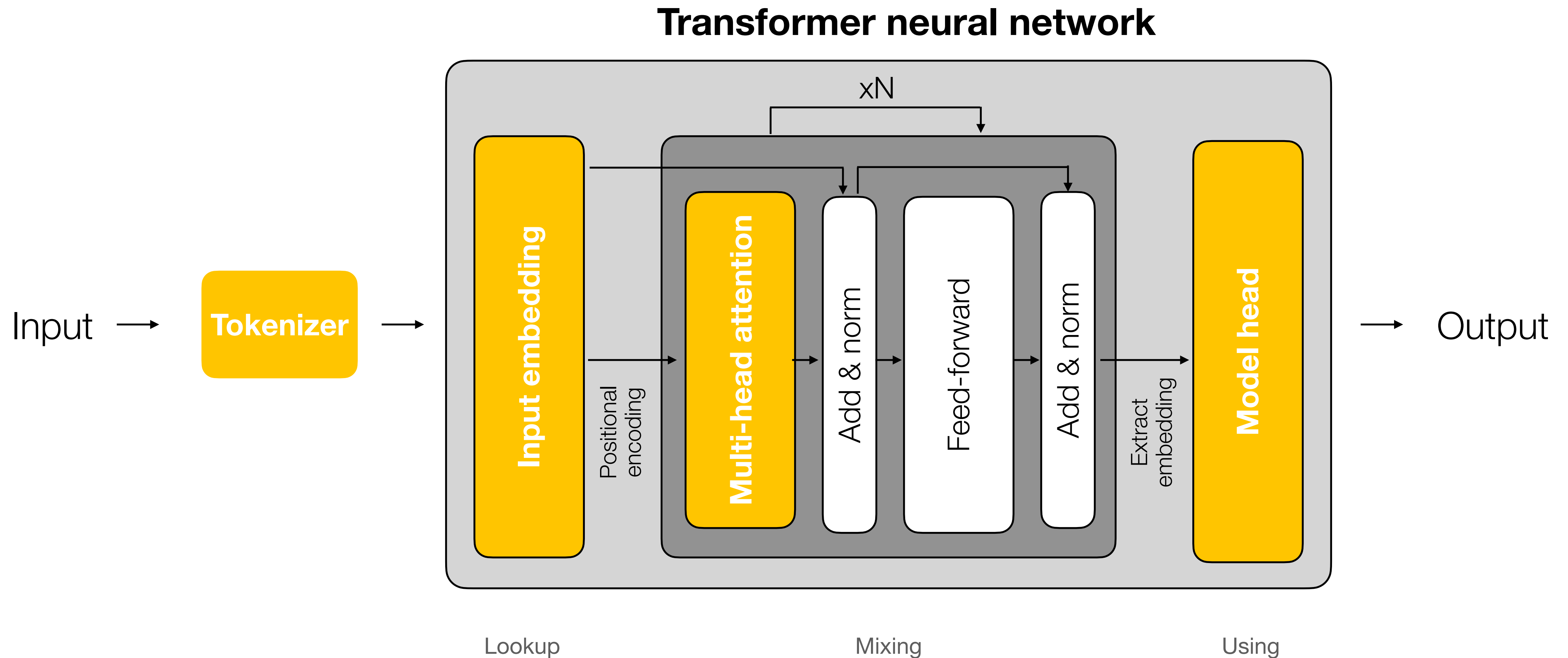


**MAX PLANCK INSTITUTE**  
FOR HUMAN DEVELOPMENT



# Transformer

## Architecture





# Transformer

## Tokenization

*Sentence*

'This was it, the descent.'



**Tokenizer**



'[CLS]', 'this', 'was', 'it', ',', 'the', 'descent', '.', '[SEP]'

"You're on your way, Kelvin. Good luck!" Moddard's voice sounded as close as before.

A wide slit opened at eye-level, and I could see the stars. The `_Prometheus_` was orbiting in the region of Alpha in Aquarius and I tried in vain to orient myself; a glittering dust filled my porthole. I could not recognize a single constellation; in this region of the galaxy the sky was unfamiliar to me. I waited for the moment when I would pass near the first distinct star, but I was unable to isolate any one of them. Their brightness was fading; they receded, merging into a vague, purplish glimmer, the sole indication of the distance I had already travelled. My body rigid, sealed in its pneumatic envelope, I was knifing through space with the impression of standing still in the void, my only distraction the steadily mounting heat.

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# Transformer

## Tokenization

*Sentence*

'...merging into a vague, purplish glimmer...'



**Tokenizer**



'merging', 'into', 'a', 'vague', ',', 'pu',  
'##rp', '##lish', 'g', '##lim', '##mer'

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I had missed the precious moment when the planet first came into view. Now it was spread out before my eyes; flat, and already immense. Nevertheless, from the appearance of its surface, I judged that I was still at a great height above it, since I had passed that imperceptible frontier after which we measure the distance that separates us from a celestial body in terms of altitude. I was falling. Now I had the sensation of falling, even with my eyes closed. (I quickly reopened them: I did not want to miss anything there was to be seen.)



# Transformer

## Tokenization

*Sentence*

'you've won 202000 Eur'



**Tokenizer**



'[CLS]', 'you', "'", 've', 'won', '2020', '##00',  
'eu', '##r', '[SEP]'

"You're on your way, Kelvin. Good luck!" Moddard's voice sounded as close as before.

A wide slit opened at eye-level, and I could see the stars. The Prometheus was orbiting in the region of Alpha in Aquarius and I tried in vain to orient myself; a glittering dust filled my porthole. I could not recognize a single constellation; in this region of the galaxy the sky was unfamiliar to me. I waited for the moment when I would pass near the first distinct star, but I was unable to isolate any one of them. Their brightness was fading; they receded, merging into a vague, purplish glimmer, the sole indication of the distance I had already travelled. My body rigid, sealed in its pneumatic envelope, I was knifing through space with the impression of standing still in the void, my only distraction the steadily mounting heat.

Suddenly, there was a shrill, grating sound, like a steel blade being drawn across a sheet of wet glass. This was it, the descent. If I had not seen the figures racing across the dial, I would not have noticed the change in direction. The stars having vanished long since, my gaze was swallowed up on the pale reddish glow of infinity. I could hear my heart thudding heavily. I could feel the coolness from the air-conditioning on my neck, although my face seemed to be on fire. I regretted not having caught a glimpse of the Prometheus, but the ship must have been out of sight by the time the automatic controls had raised the shutter of my porthole.

The capsule was shaken by a sudden jolt, then another. The whole vehicle began to vibrate. Filtered through the insulating layers of the outer skins, penetrating my pneumatic cocoon, the vibration reached me, and ran through my entire body. The image of the dial shivered and multiplied, and its phosphorescence spread out in all directions. I felt no fear. I had not undertaken this long voyage only to overshoot my target!

I called into the microphone:

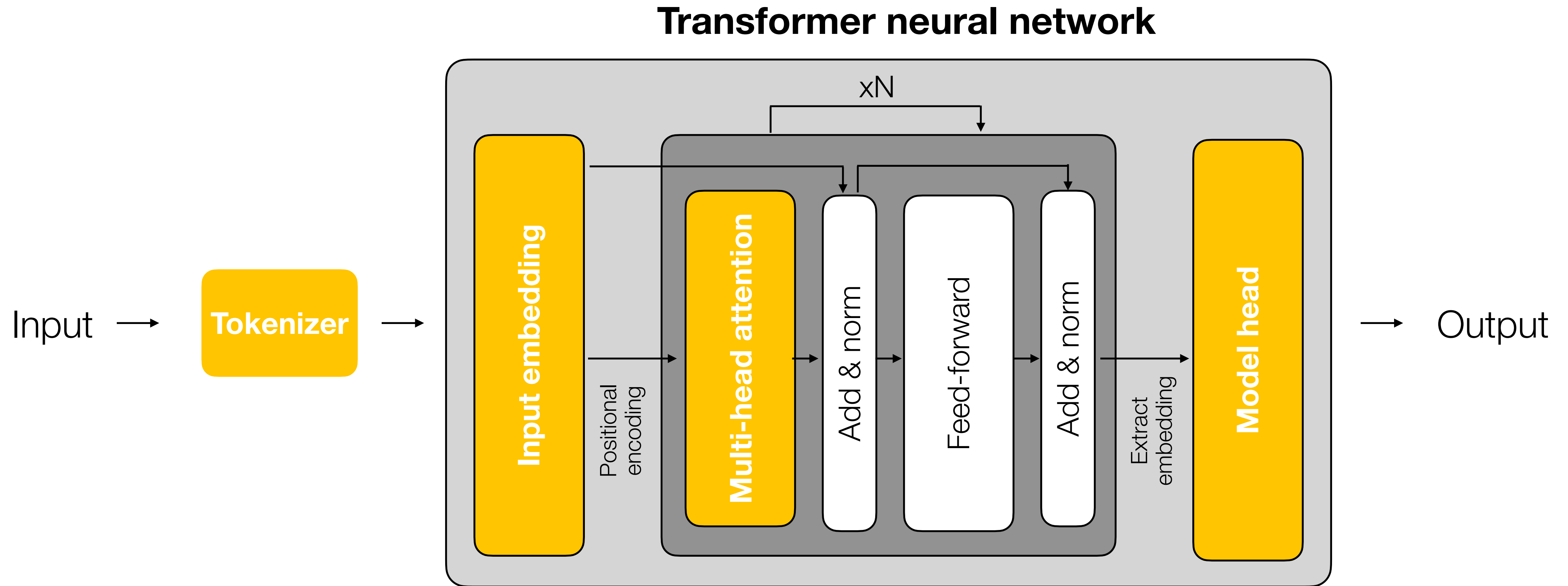
"Station Solaris! Station Solaris! Station Solaris! I think I am leaving the flight-path, correct my course! Station Solaris, this is the Prometheus capsule. Over."

I had missed the precious moment when the planet first came into view. Now it was spread out before my eyes; flat, and already immense. Nevertheless, from the appearance of its surface, I judged that I was still at a great height above it, since I had passed that imperceptible frontier after which we measure the distance that separates us from a celestial body in terms of altitude. I was falling. Now I had the sensation of falling, even with my eyes closed. (I quickly reopened them: I did not want to miss anything there was to be seen.)



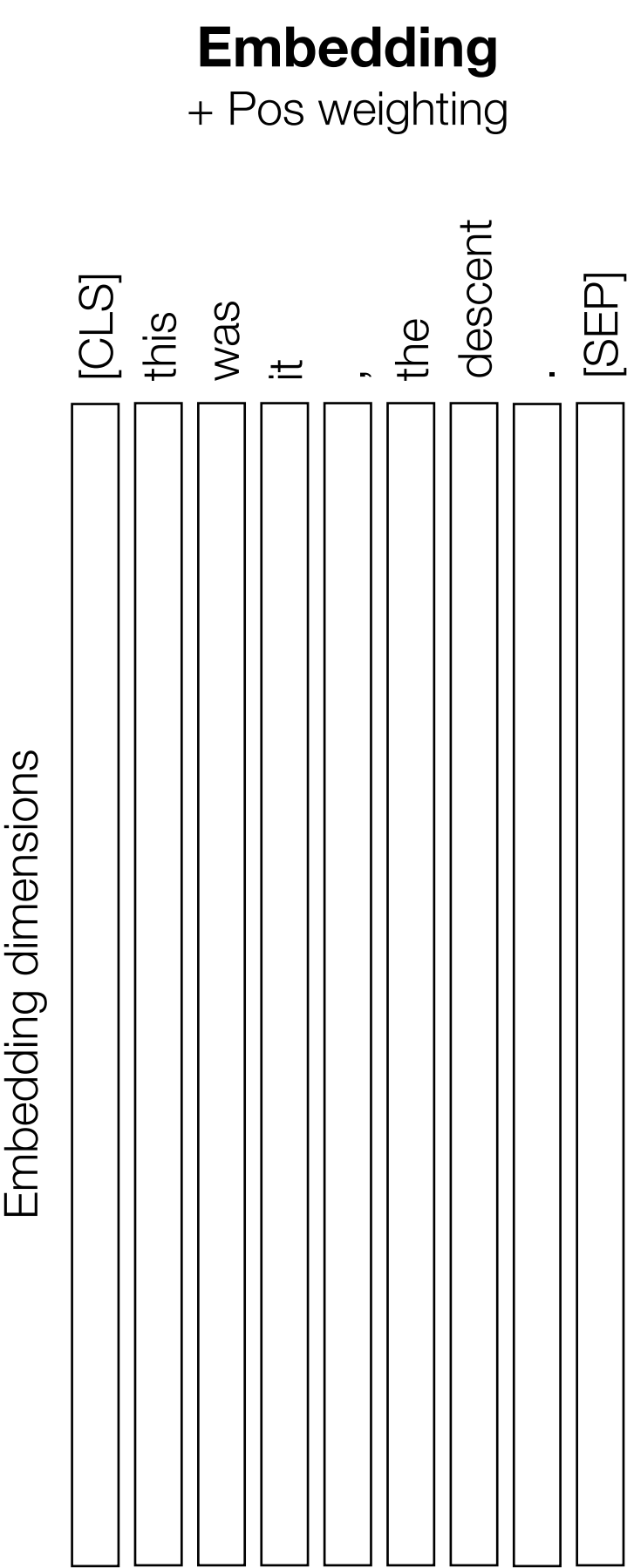
# Transformer

## Architecture



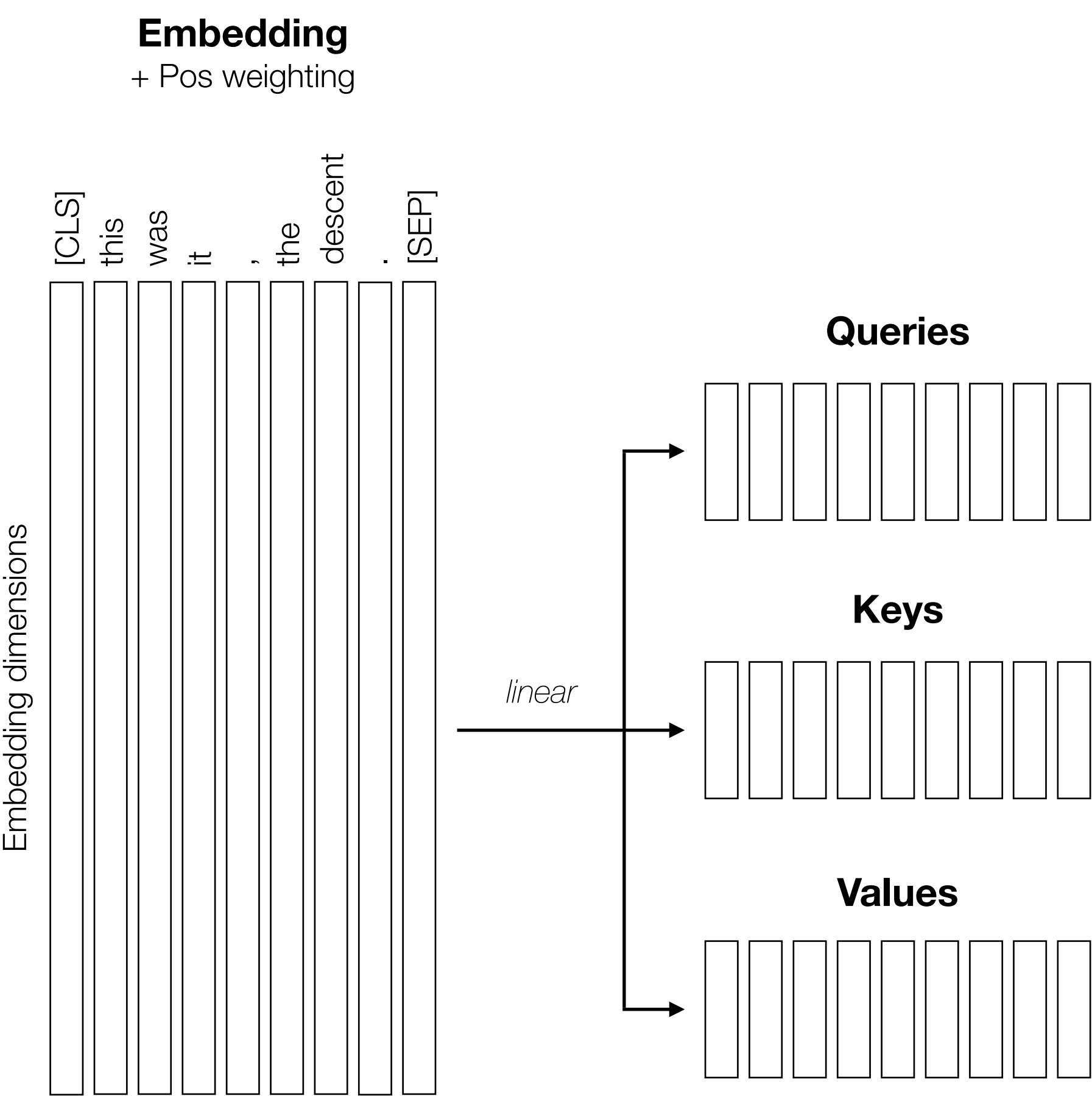
# Transformer

## Input embeddings



# Transformer

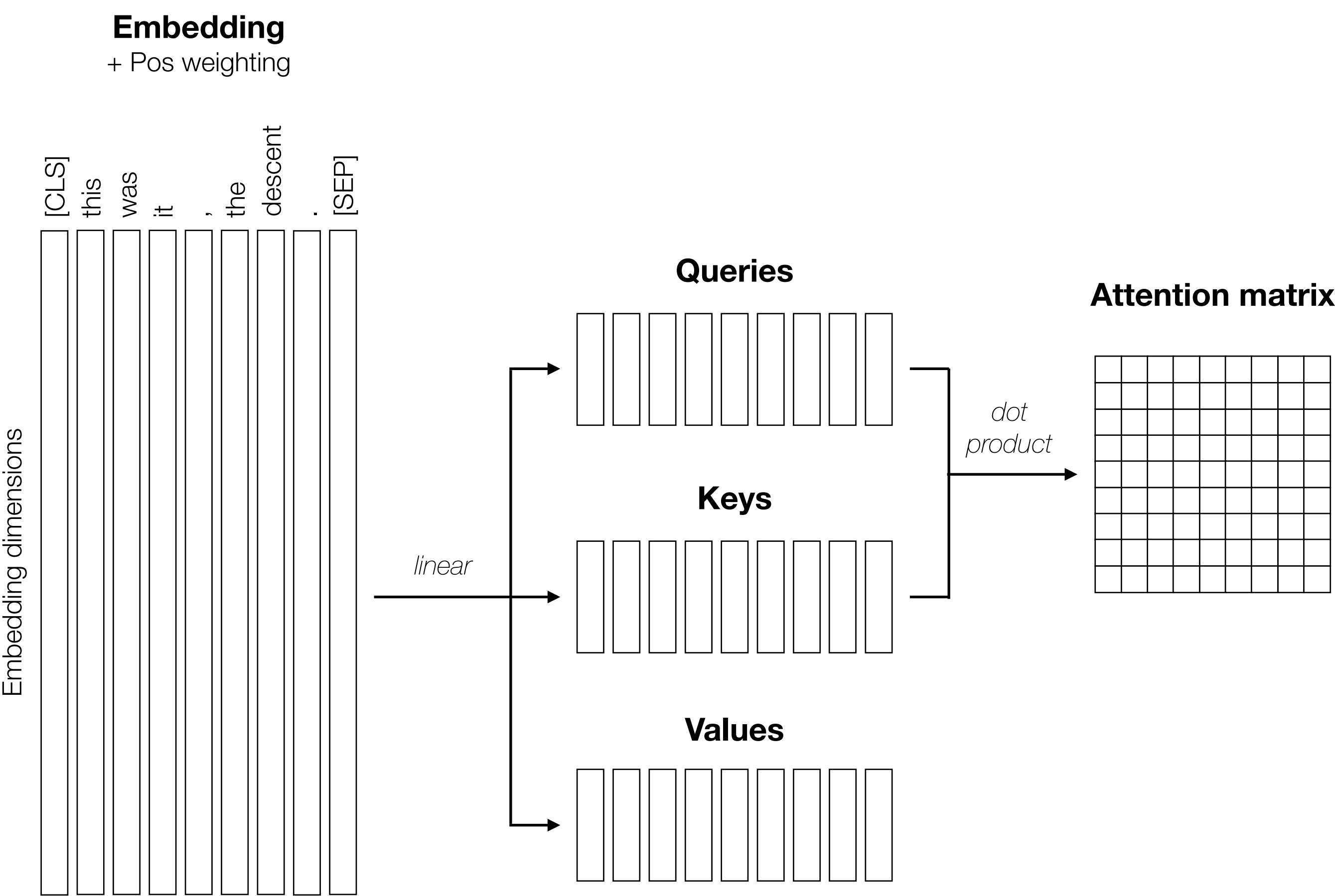
## Attention





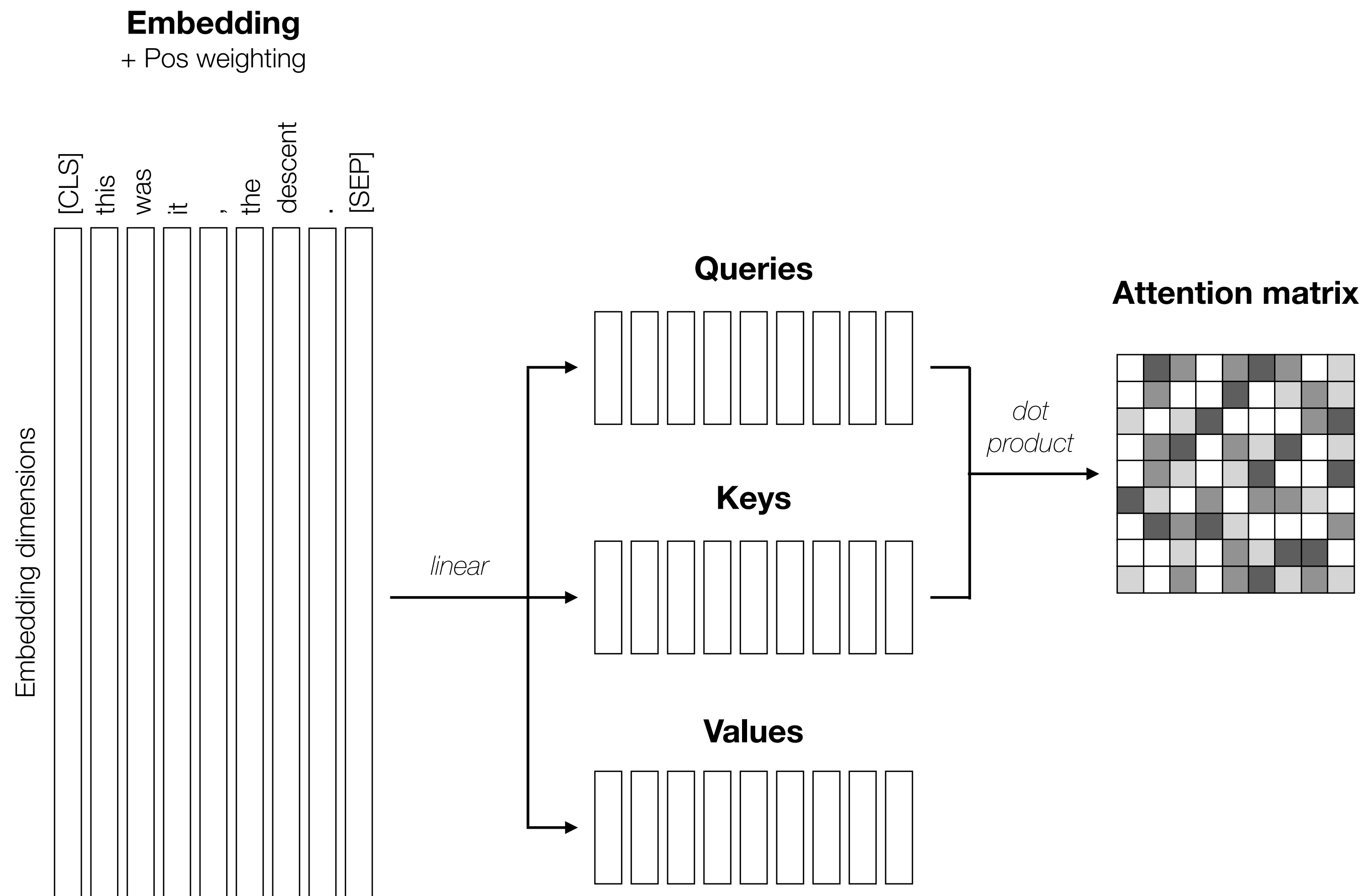
# Transformer

## Attention



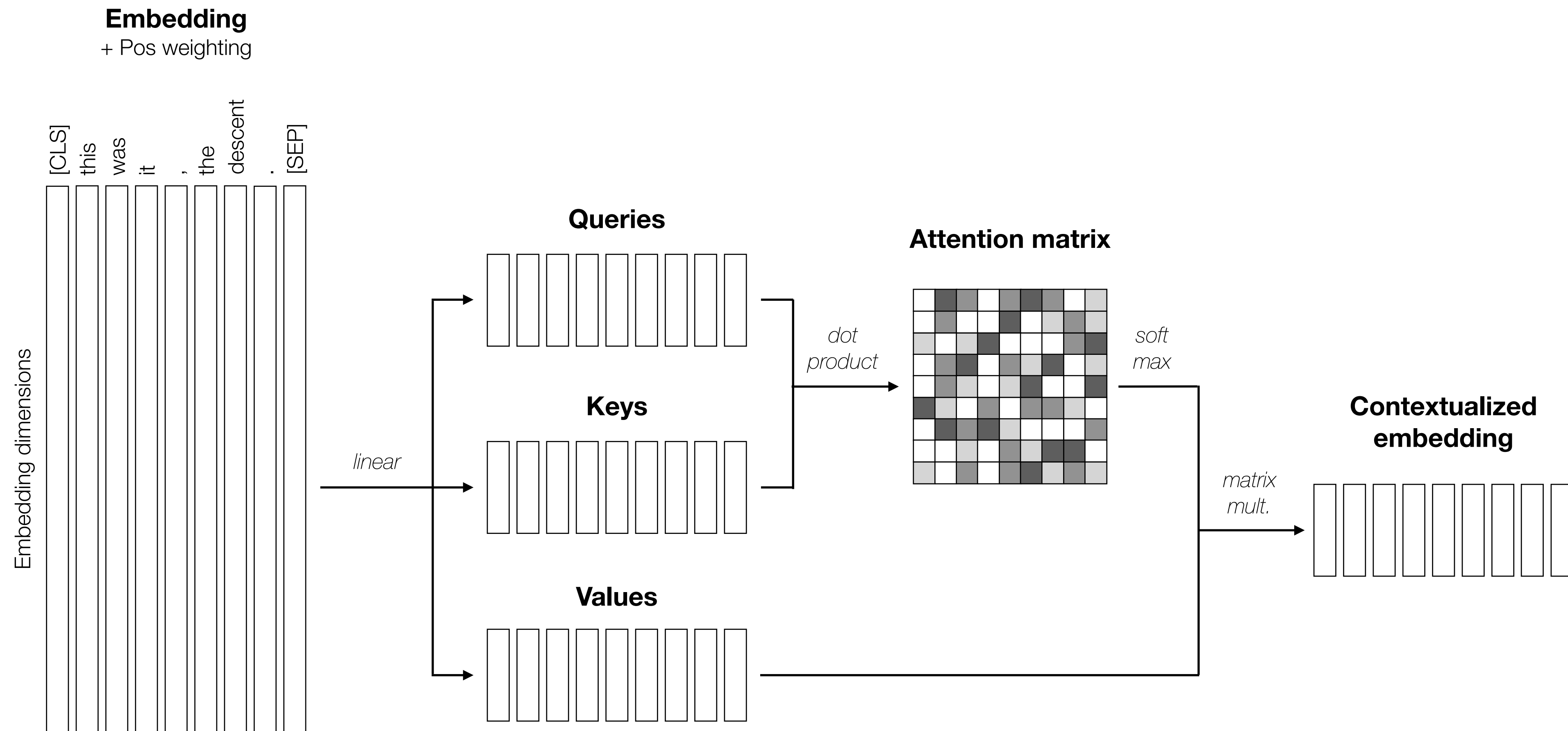
# Transformer

## Attention



# Transformer

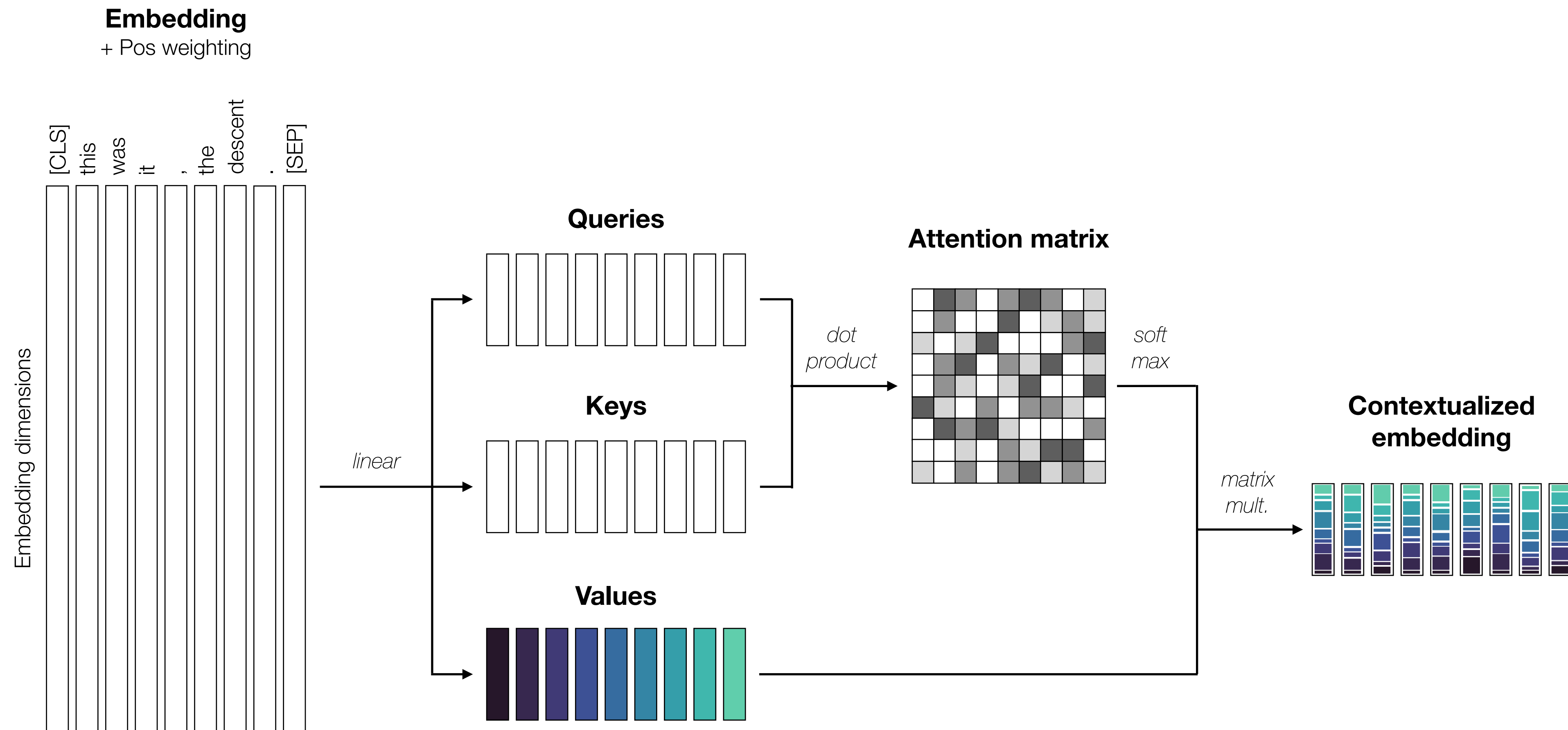
## Attention





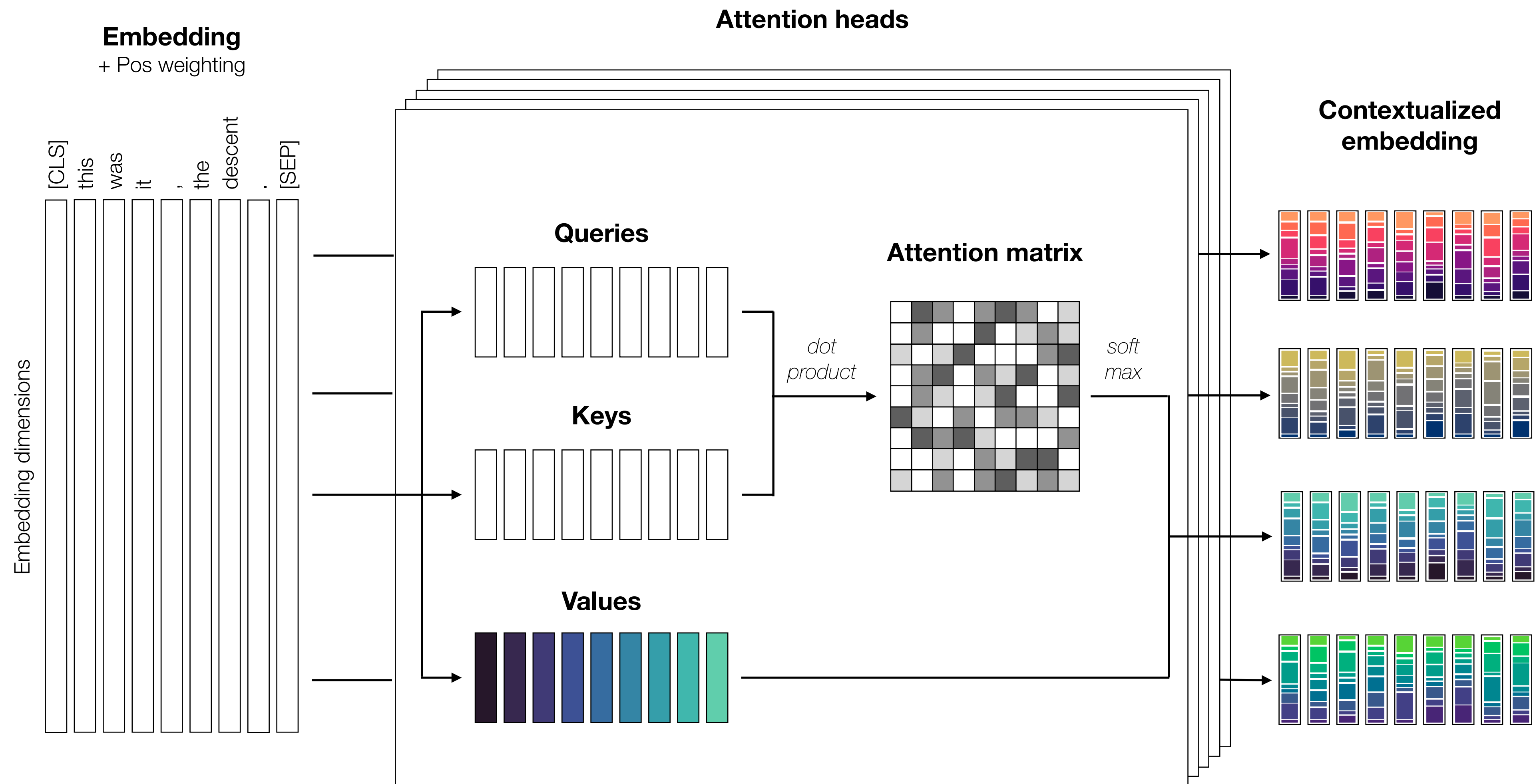
# Transformer

## Attention



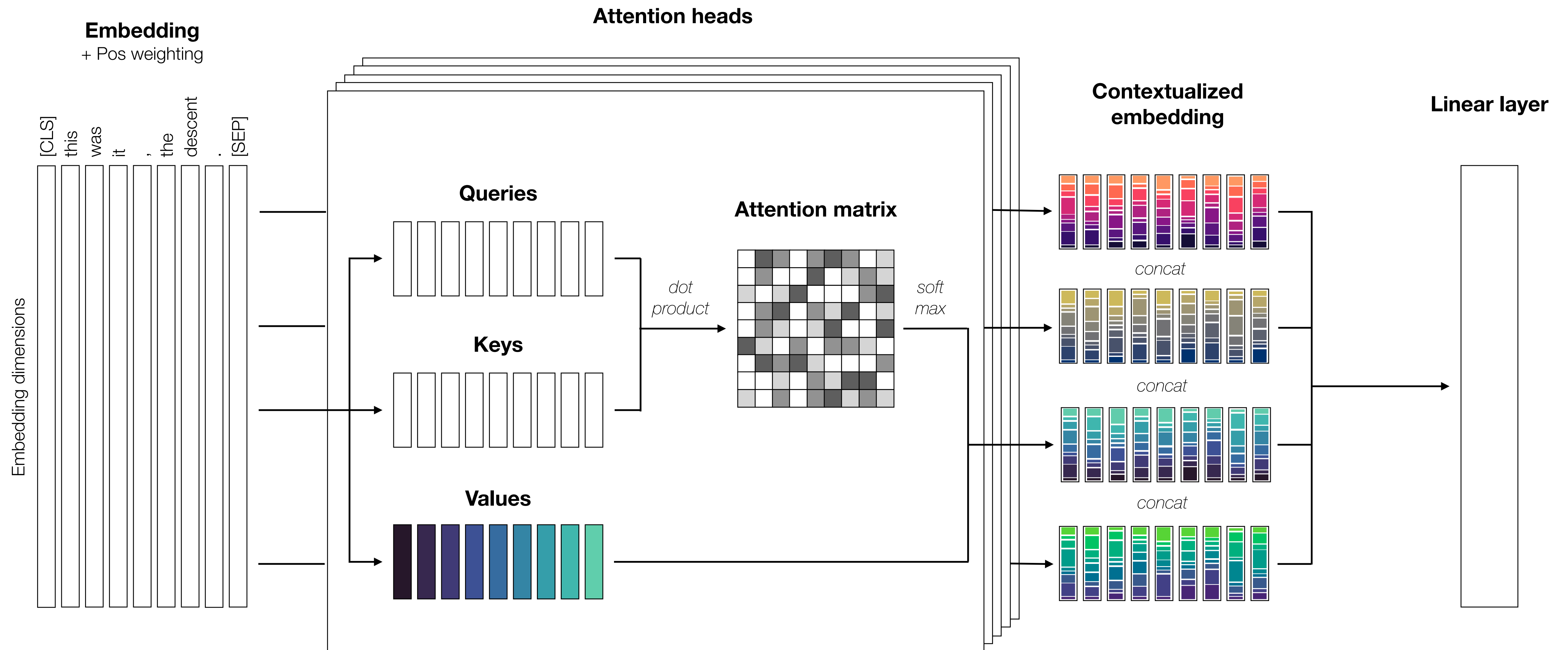
# Transformer

## Attention



# Transformer

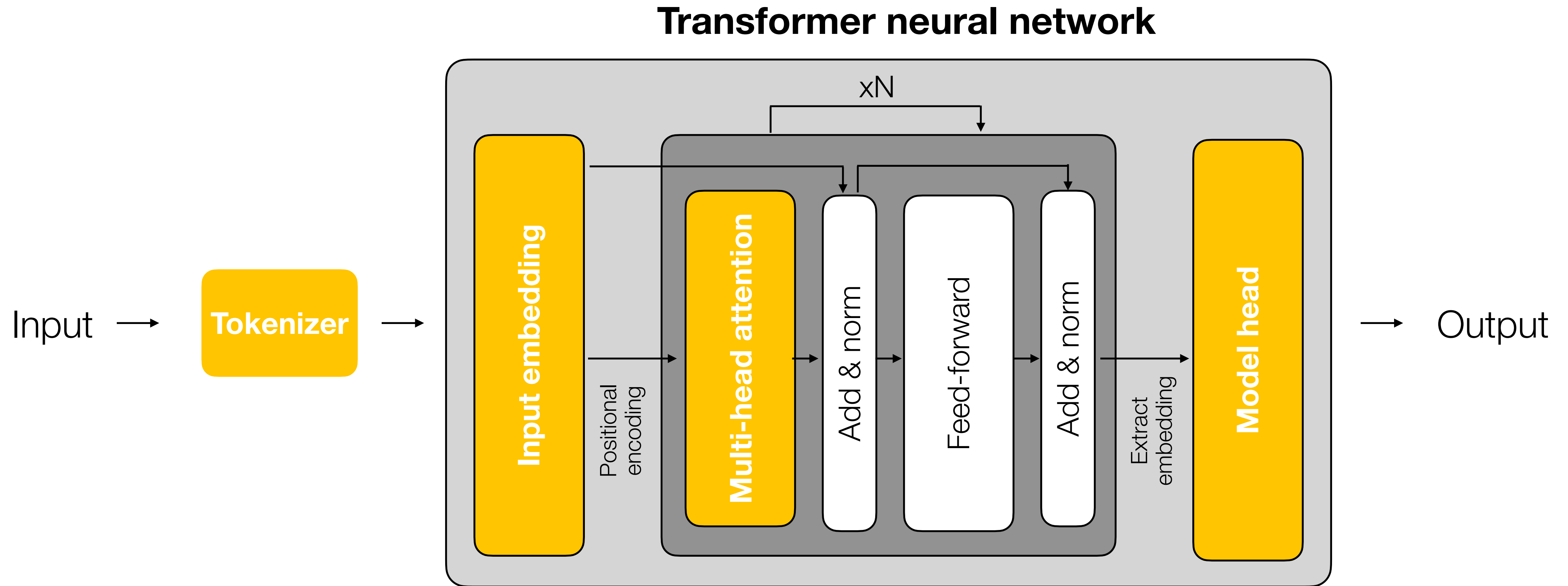
## Attention





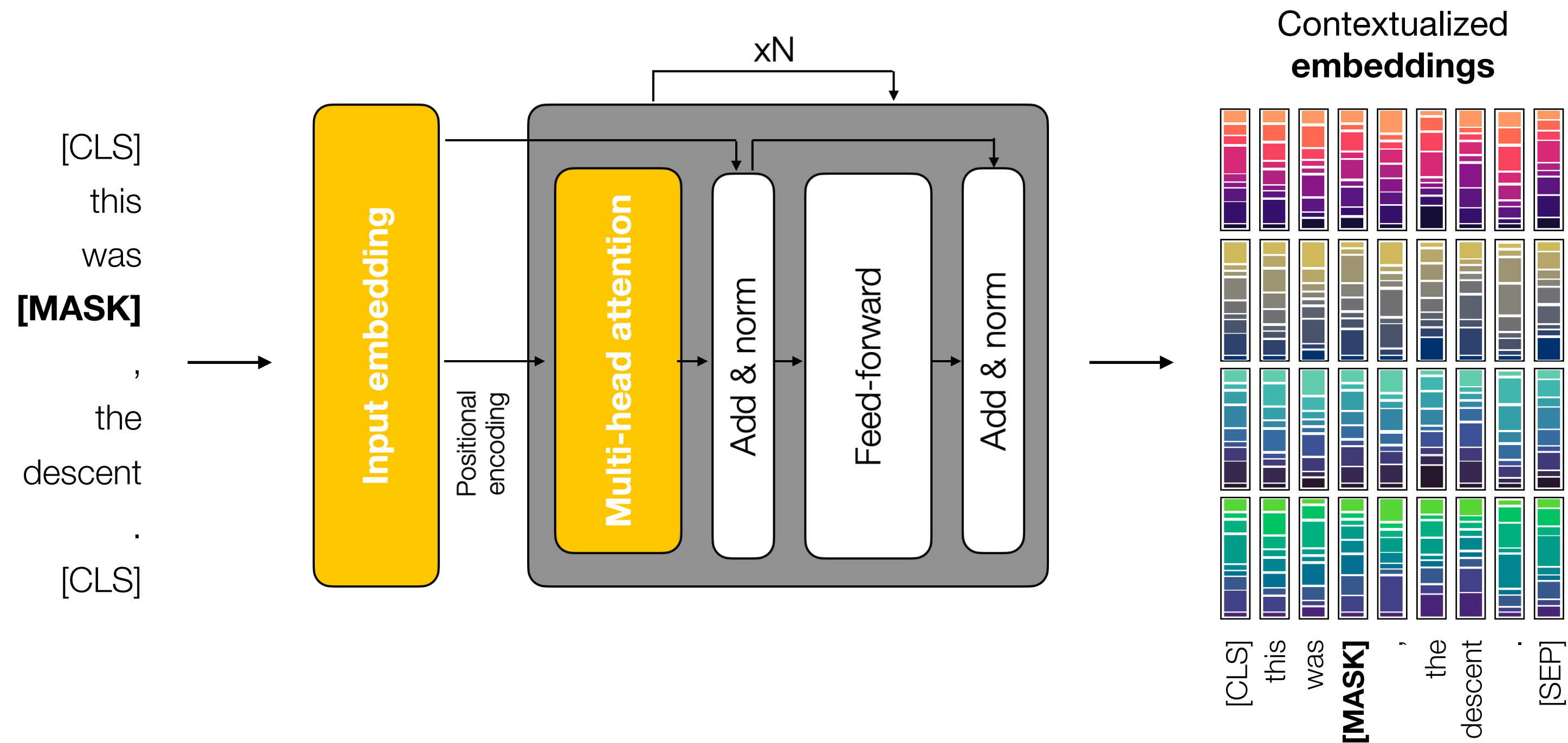
# Transformer

## Architecture



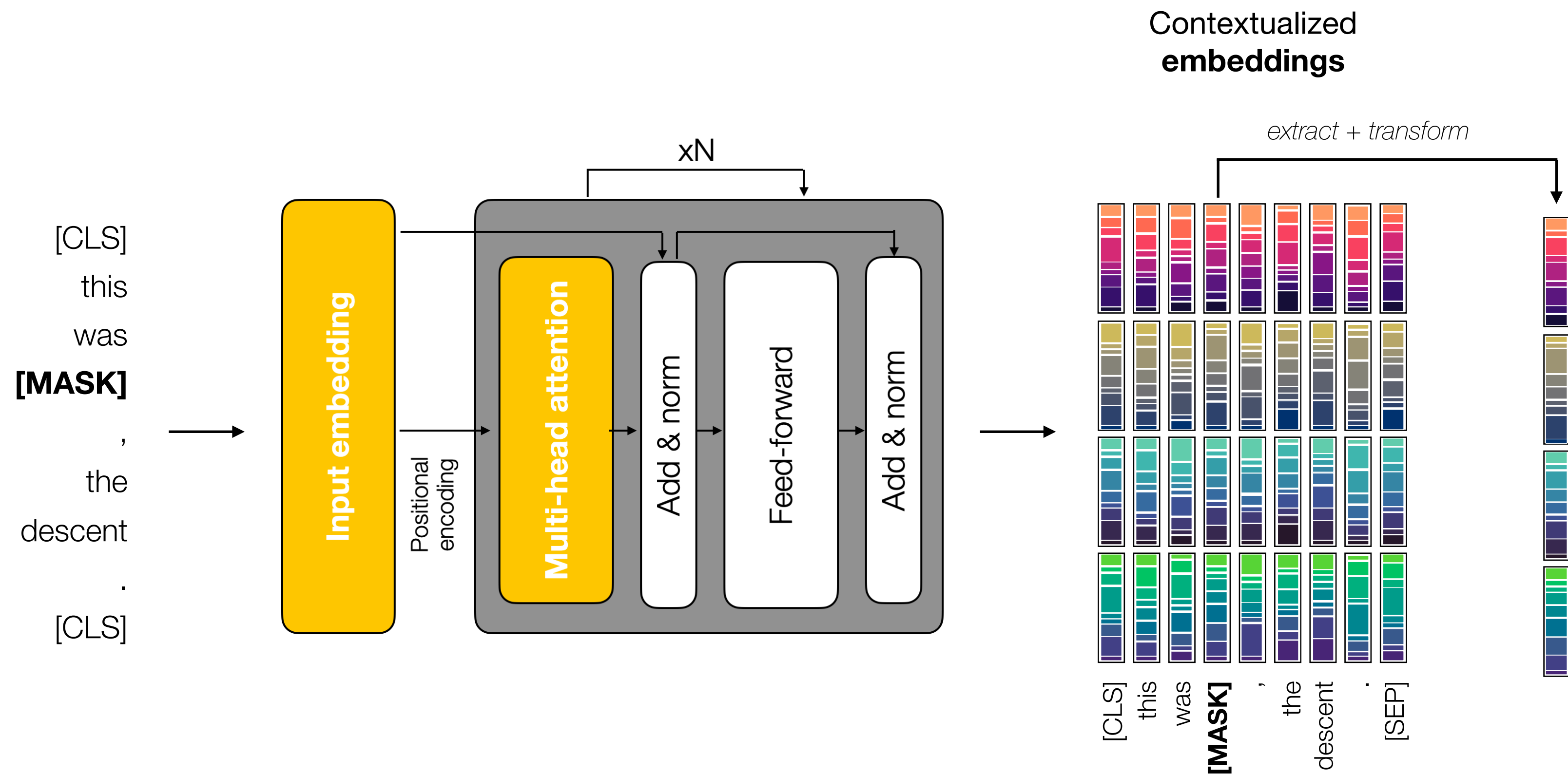
# Transformer

Model head for **masked language modeling**



# Transformer

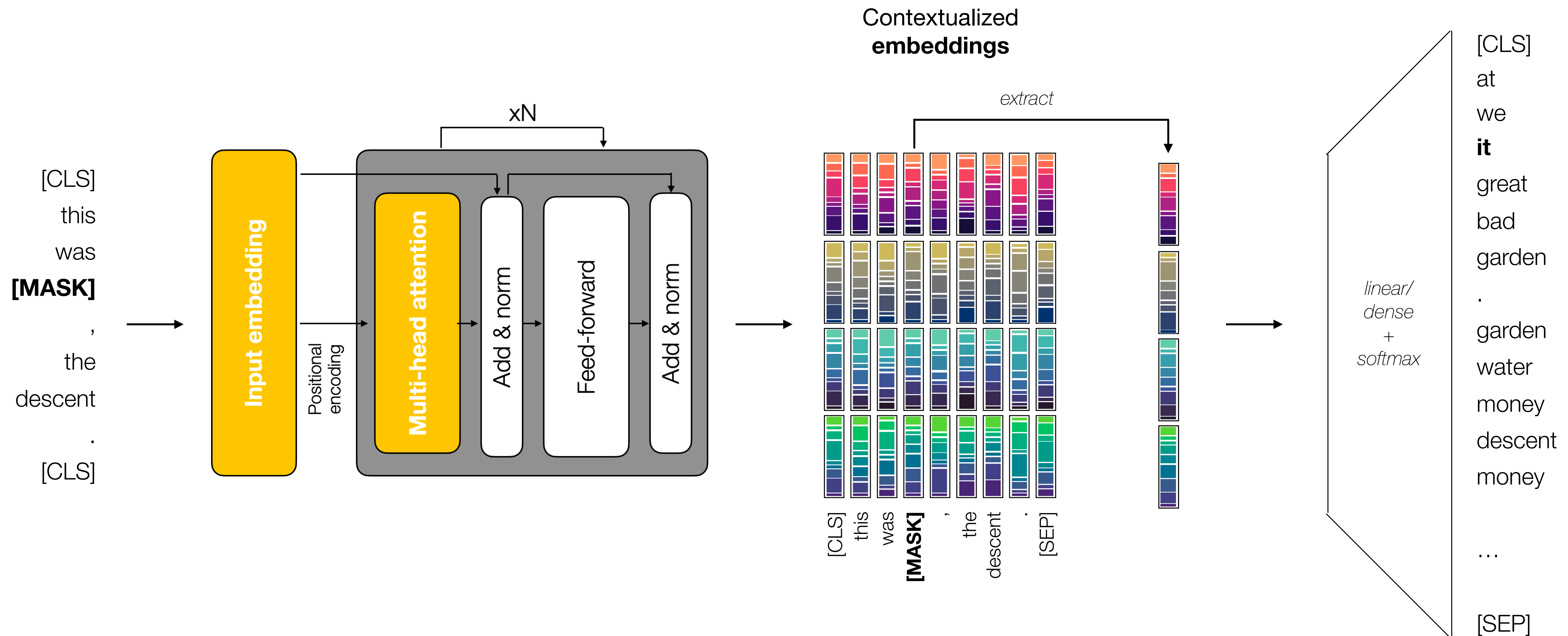
## Model head for masked language modeling





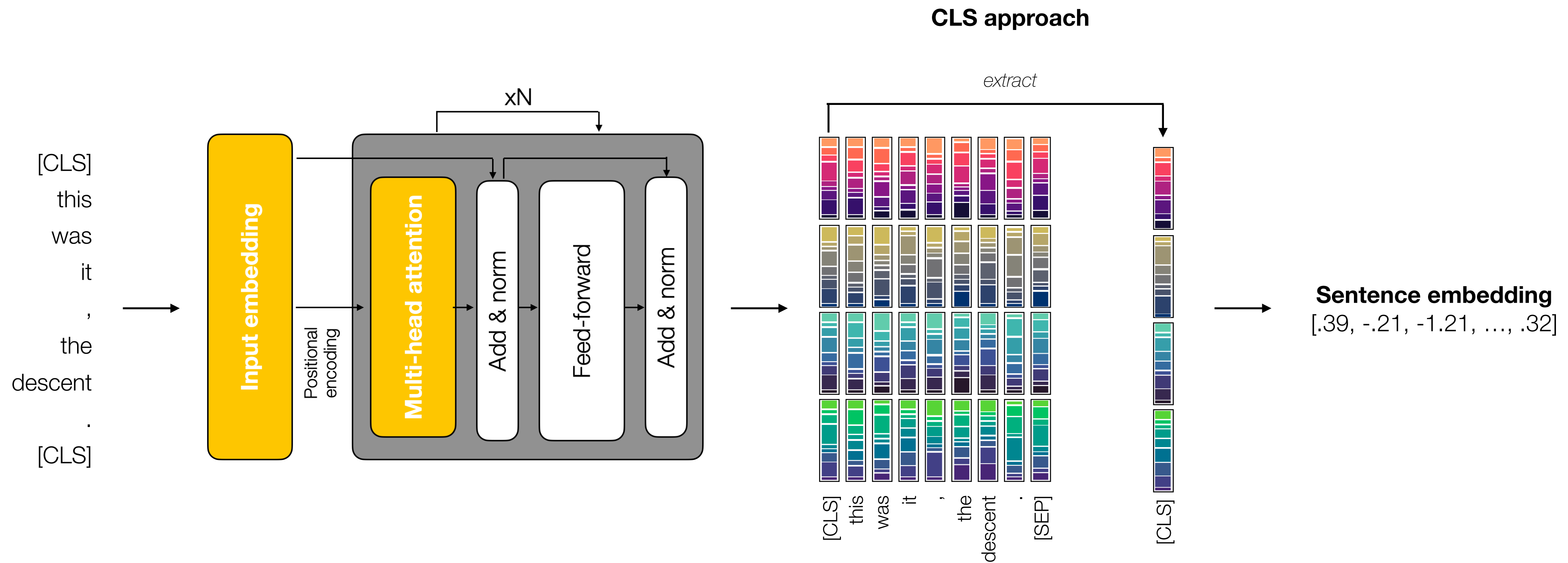
# Transformer

## Model head for masked language modeling



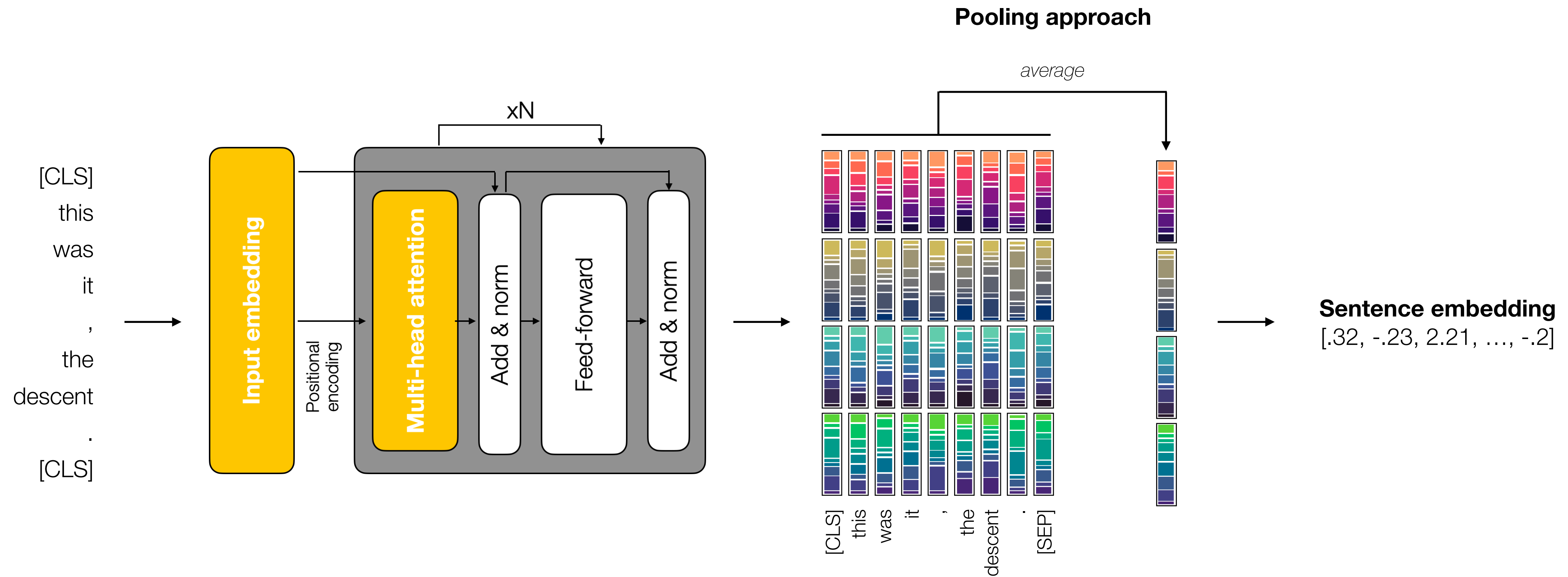
# Feature extraction

to generate sentence embeddings



# Feature extraction

to generate sentence embeddings



# Exercise

Using **feature extraction** to analyze personality survey items

factor	construct	item
Openness	Emotionality	Enjoy examining myself and my life.
Neuroticism	Immoderation	Do things I later regret.
Openness	Liberalism	Tend to vote for liberal political candidates.
Conscientiousness	Orderliness	Like to tidy up.
Conscientiousness	Achievement-Striving	Plunge into tasks with all my heart.
Neuroticism	Anger	Seldom get mad.
Conscientiousness	Achievement-Striving	Demand quality.
Agreeableness	Trust	Believe that others have good intentions.
Neuroticism	Self-consciousness	Only feel comfortable with friends.
Agreeableness	Morality	Would never cheat on my taxes.
Openness	Aesthetic Appreciation/Artistic Interests	Do not enjoy going to art museums.
Neuroticism	Anxiety	Worry about things.
Conscientiousness	Achievement-Striving	Do just enough work to get by.
Neuroticism	Immoderation	Love to eat.
Agreeableness	Altruism	Have a good word for everyone.
Agreeableness	Modesty/Humility	Dislike talking about myself.
Conscientiousness	Self-Discipline	Am always prepared.
Conscientiousness	Dutifulness	Tell the truth.



# Quiz



**MAX PLANCK INSTITUTE**  
FOR HUMAN DEVELOPMENT



# Quiz

How is meaning operationalized in language models?

What is a transformer and what components do you know?

What is attention?

What is feature extraction and how does it work?