BIU NLP

Thinking Like Transformers

Gail Weiss, Yoav Goldberg, Eran Yahav

European Research Council

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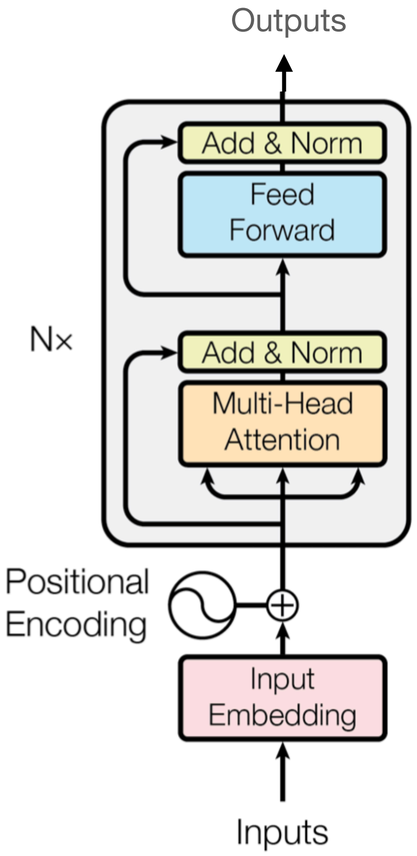
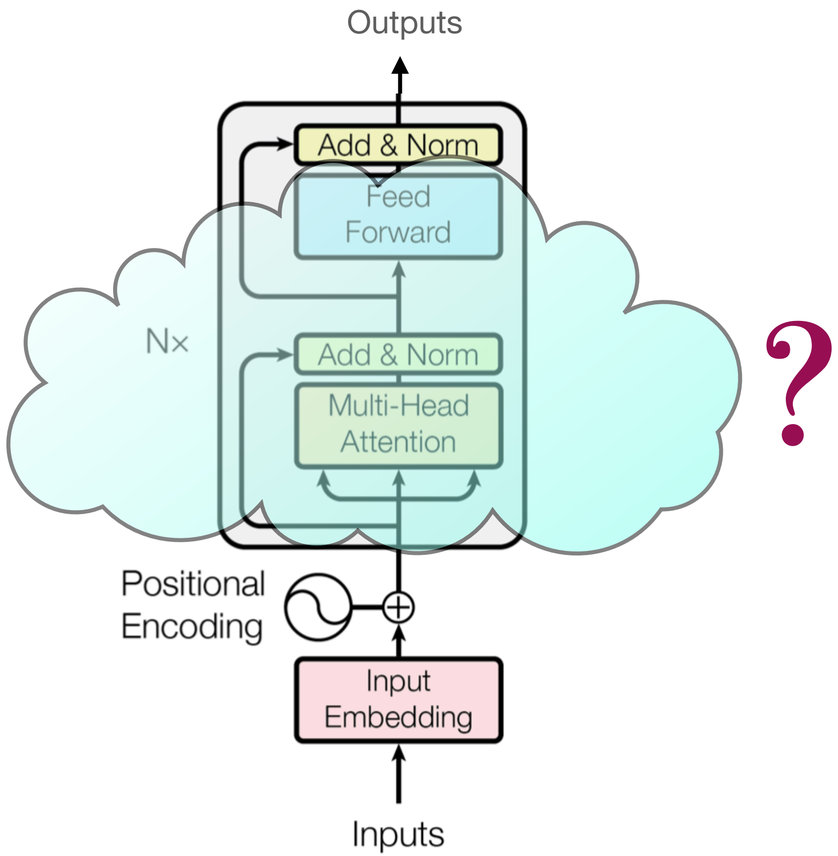
Transformers are very effective



Transformers are very effective

But we don't know how they work



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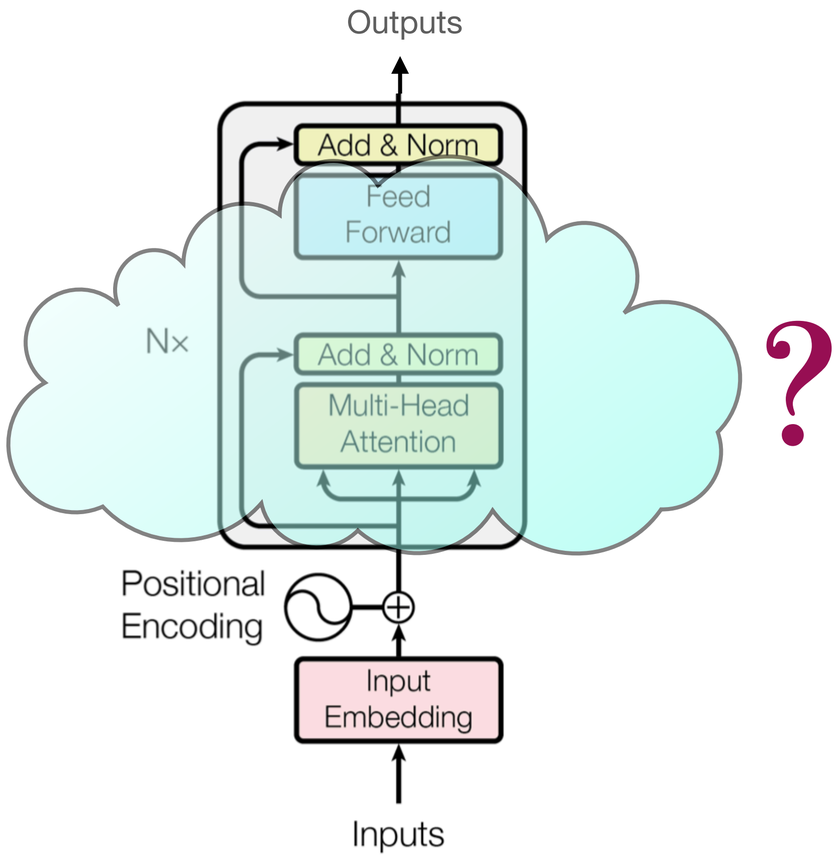
Question

What is the computational model of the Transformer-encoder?



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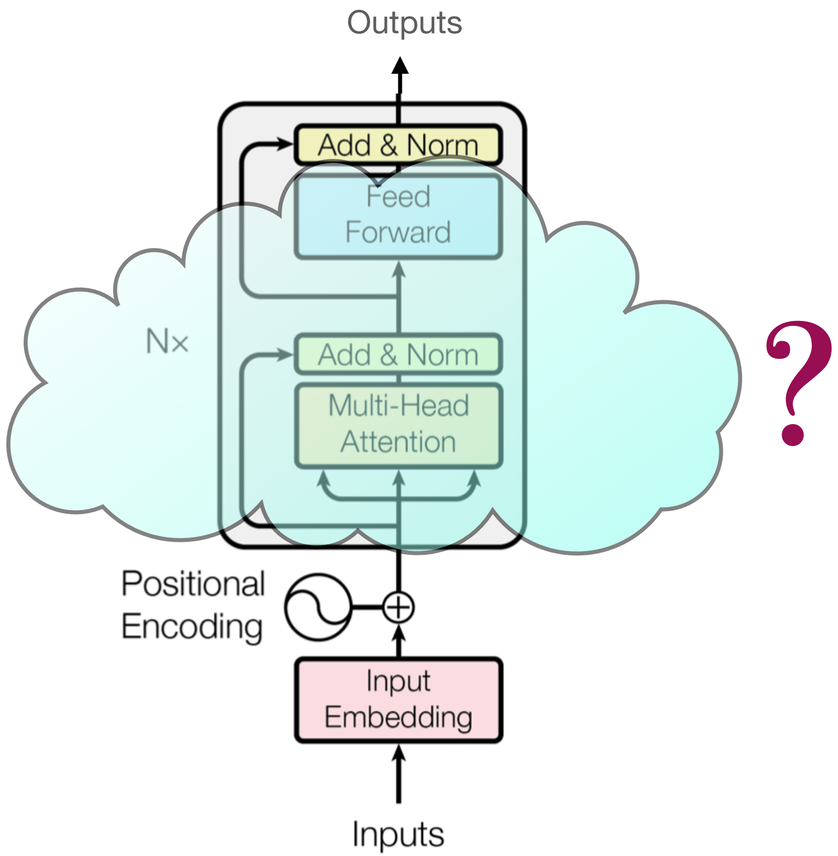
Can it solve “Reverse”?

abcde ↦ edcba



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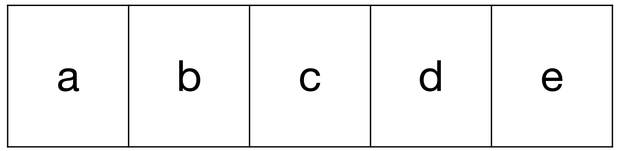
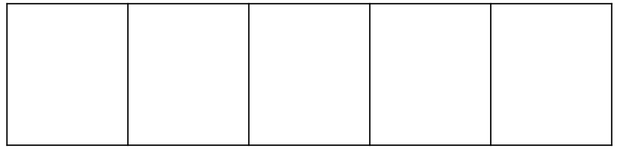


"standard" programming language



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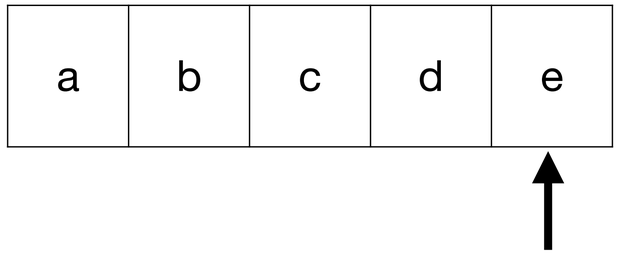

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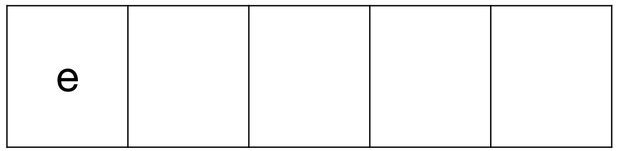

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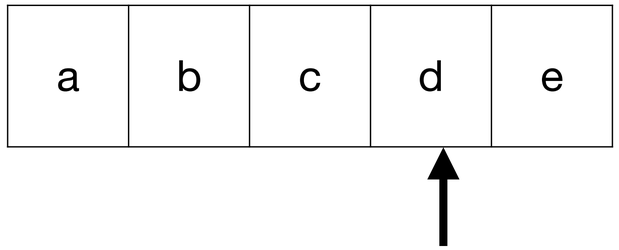

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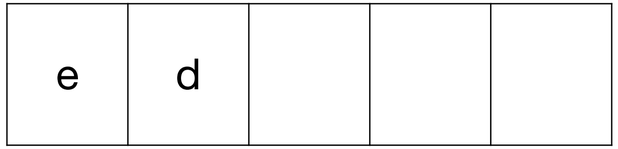

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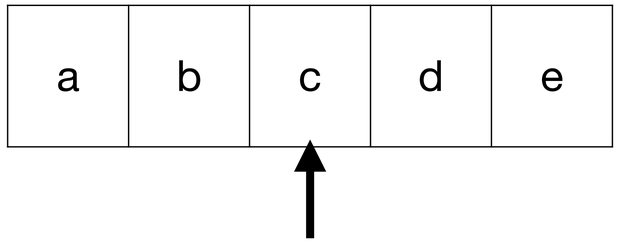

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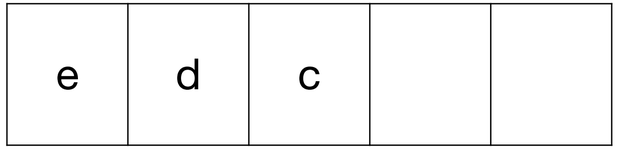

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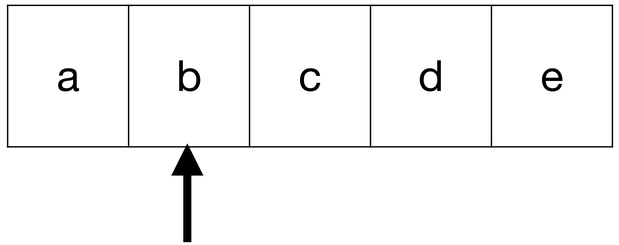

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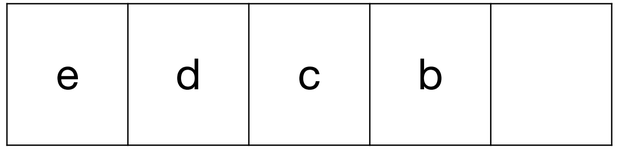

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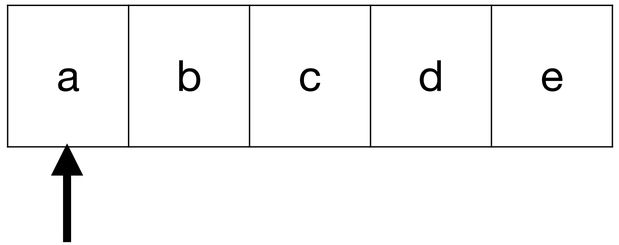

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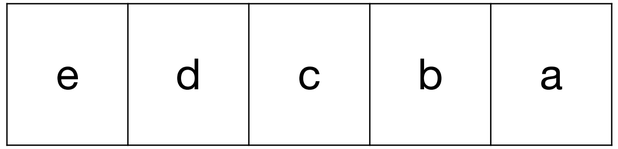

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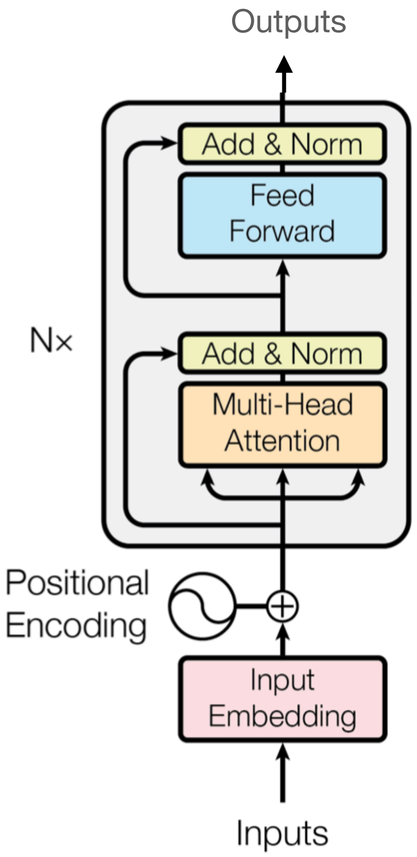

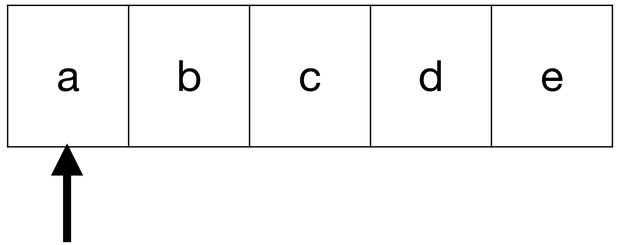

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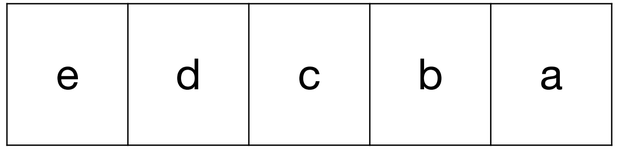

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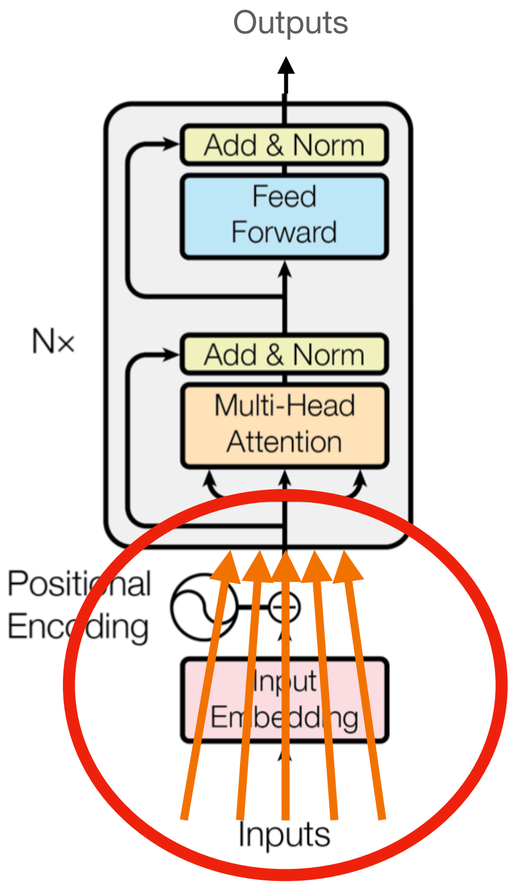

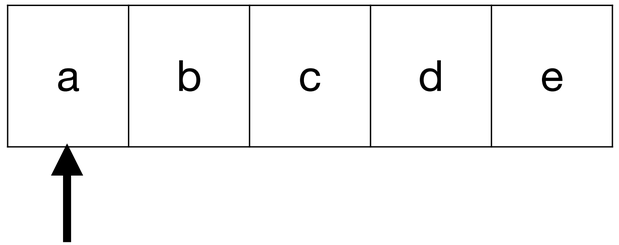

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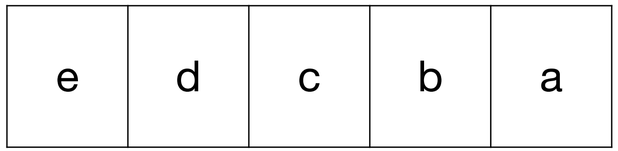

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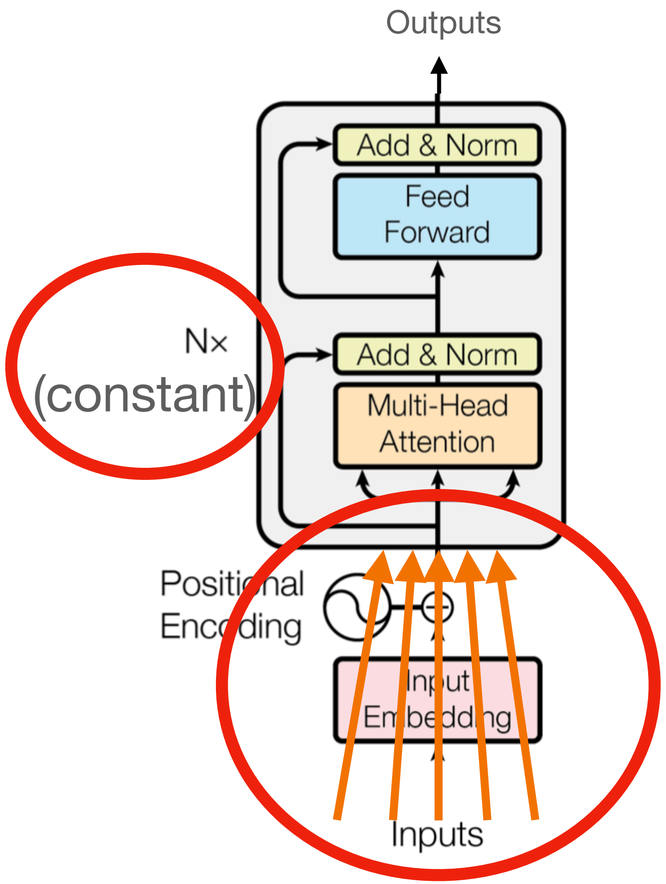

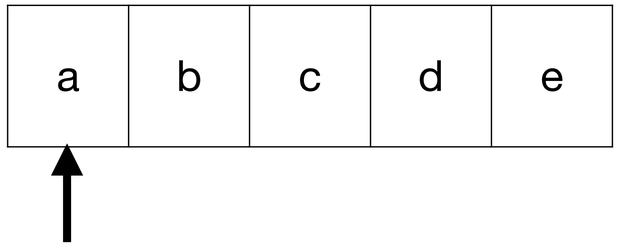

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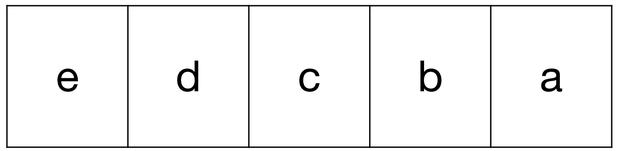

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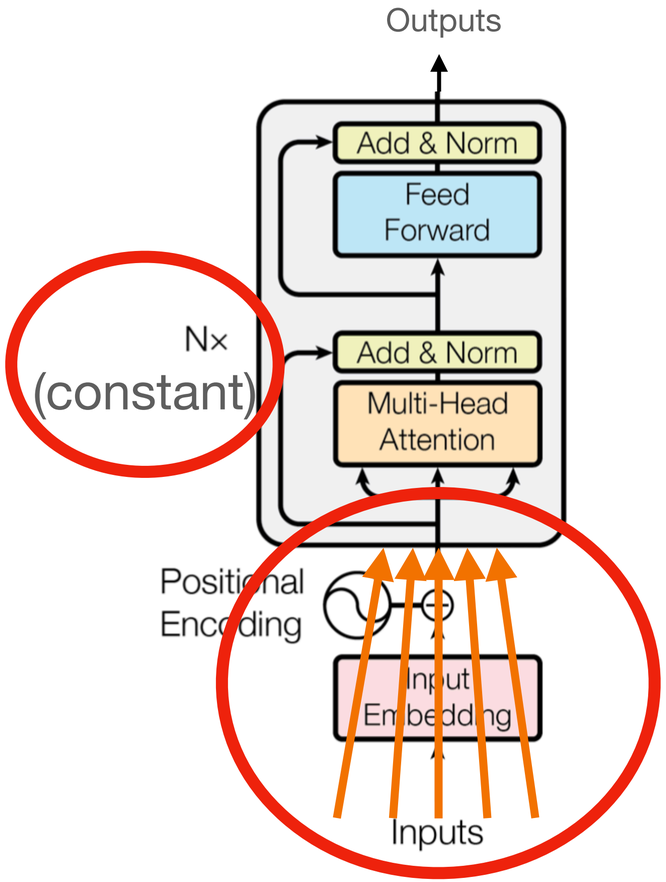

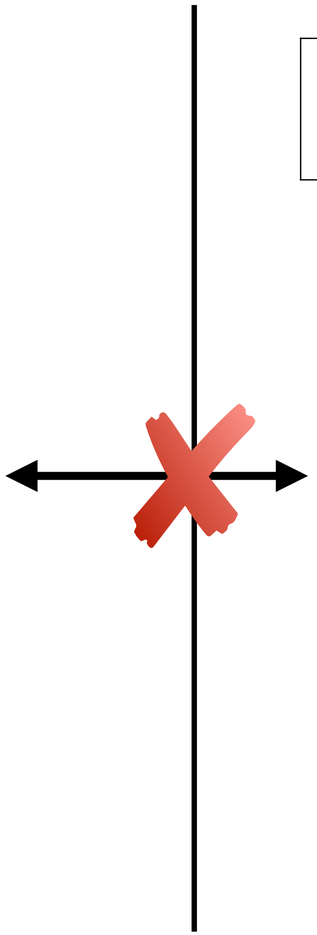

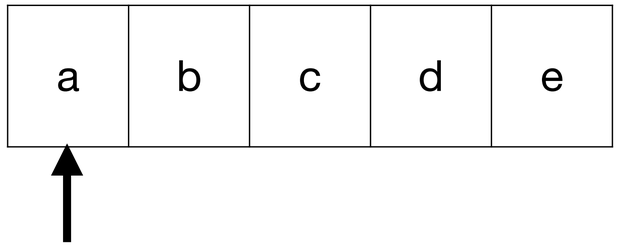

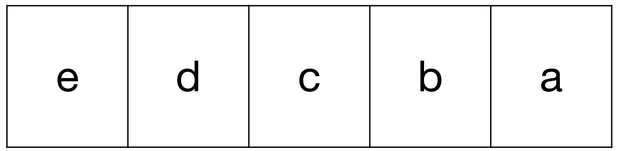

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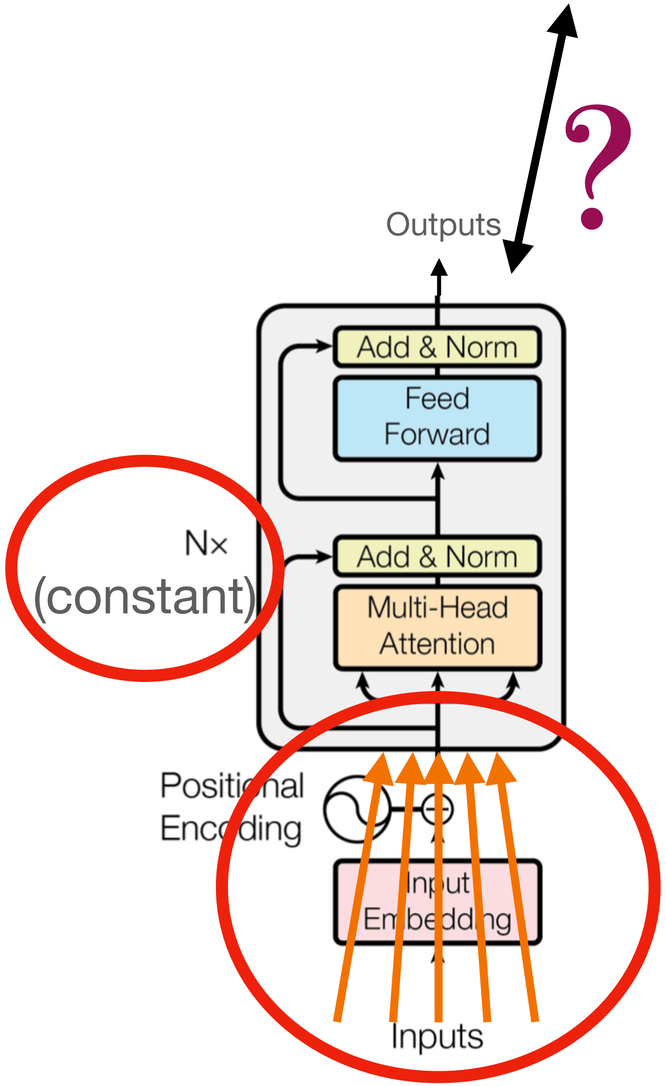

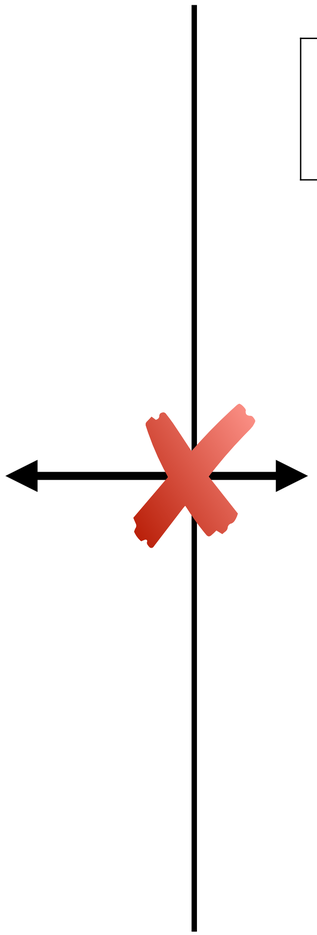

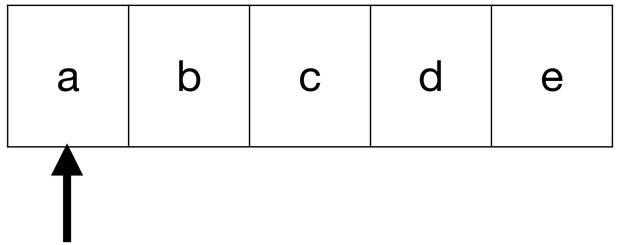

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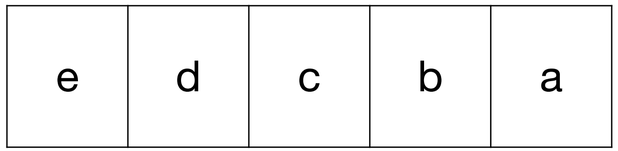
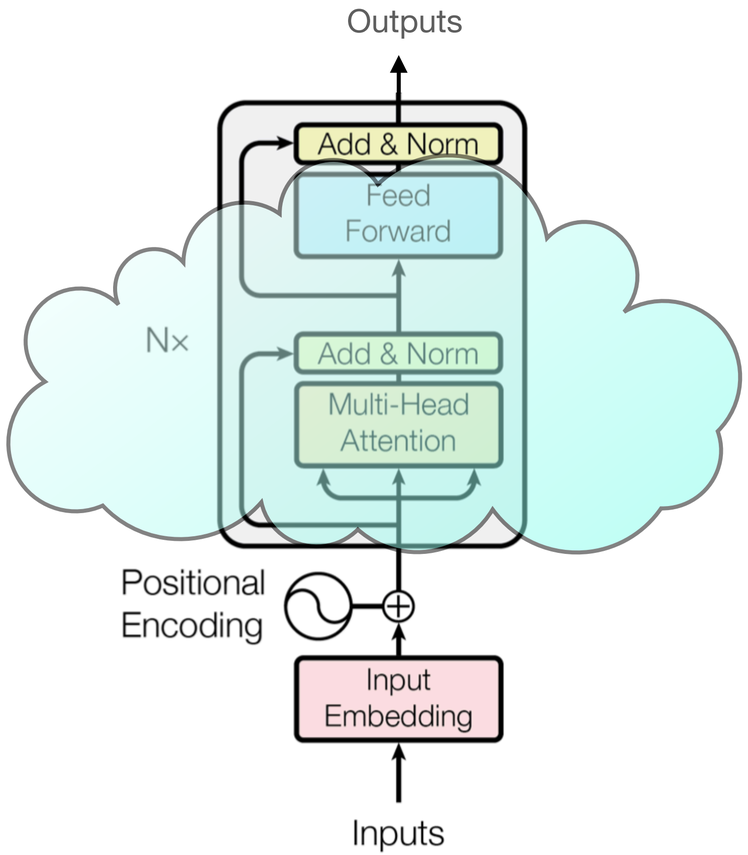


RASP

Restricted Access Sequence Processing



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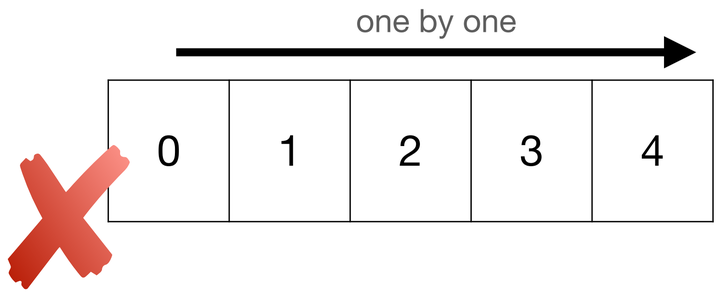

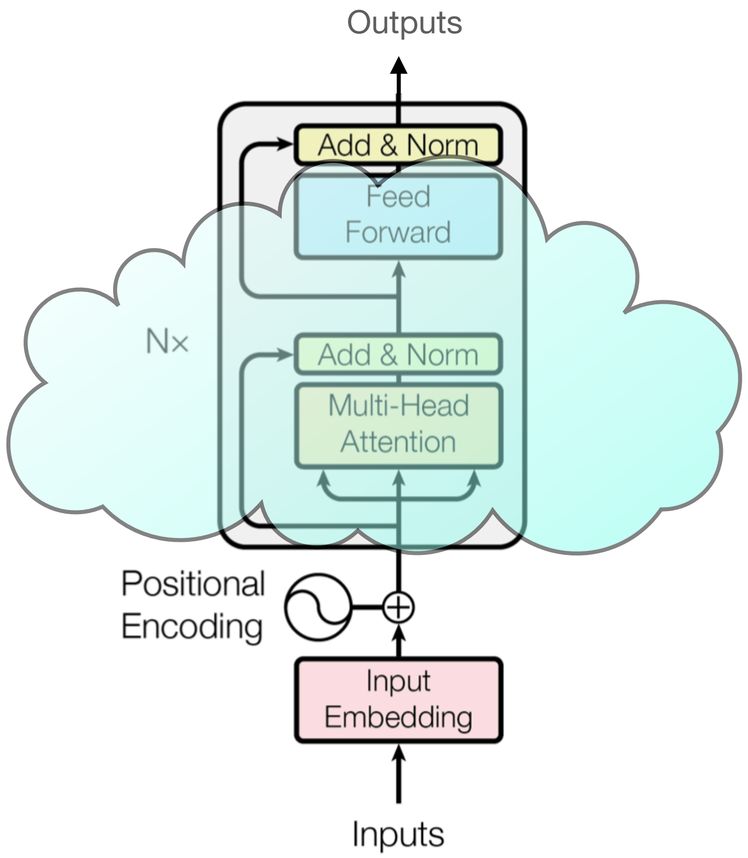

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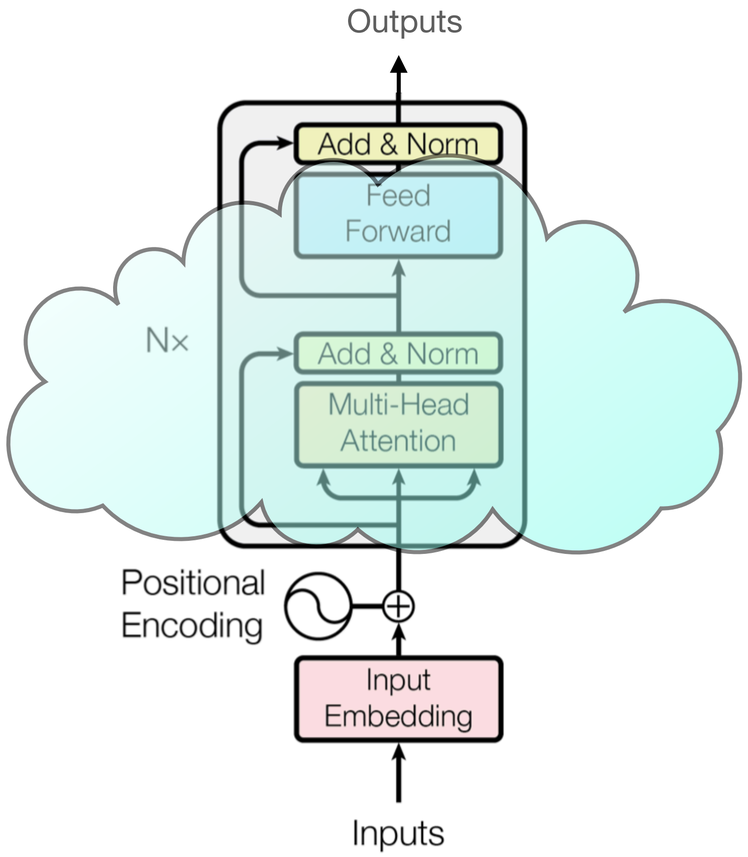

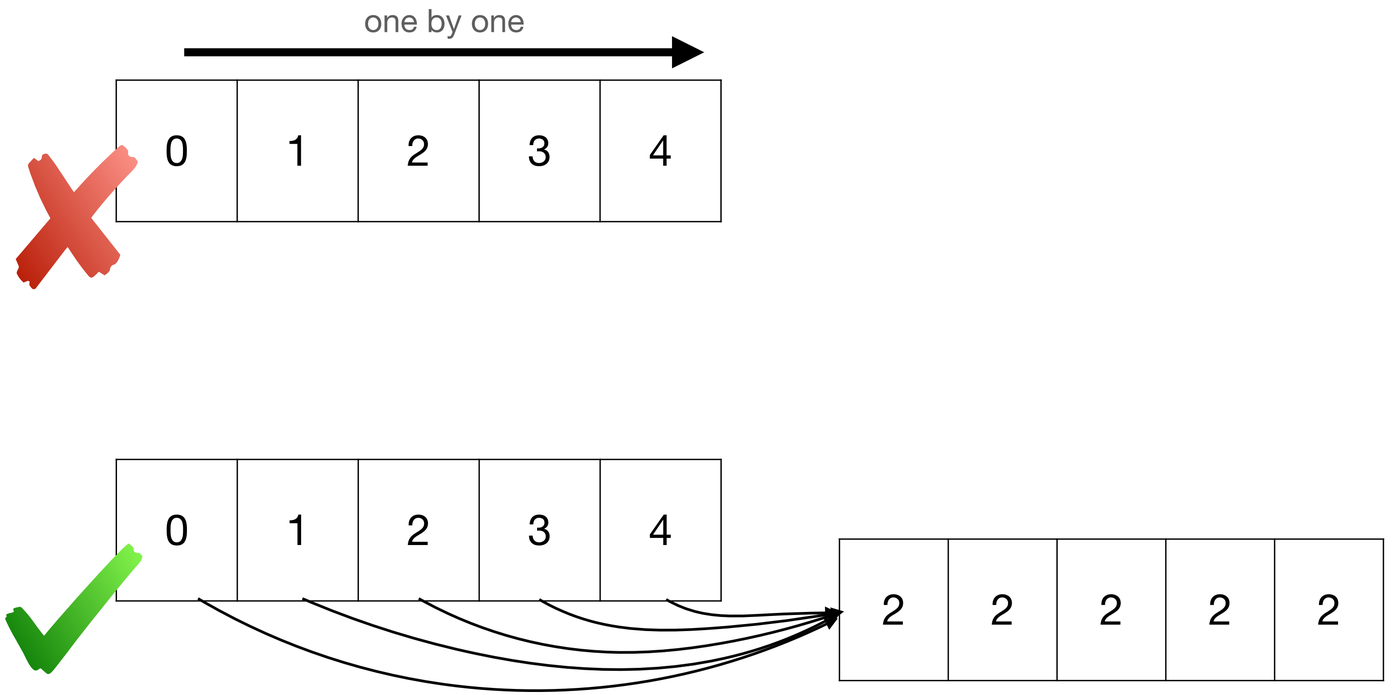

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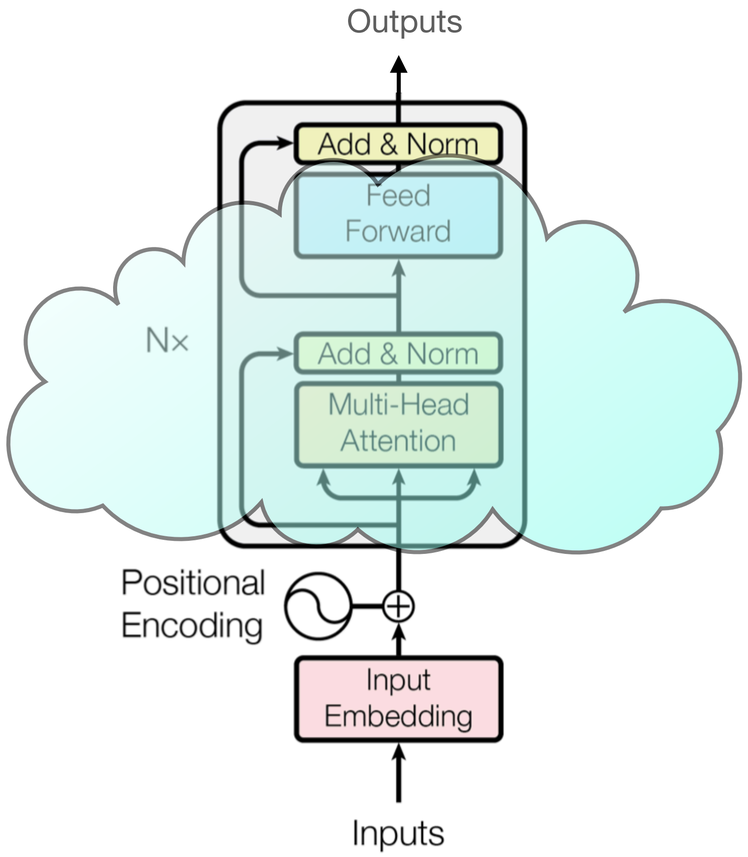

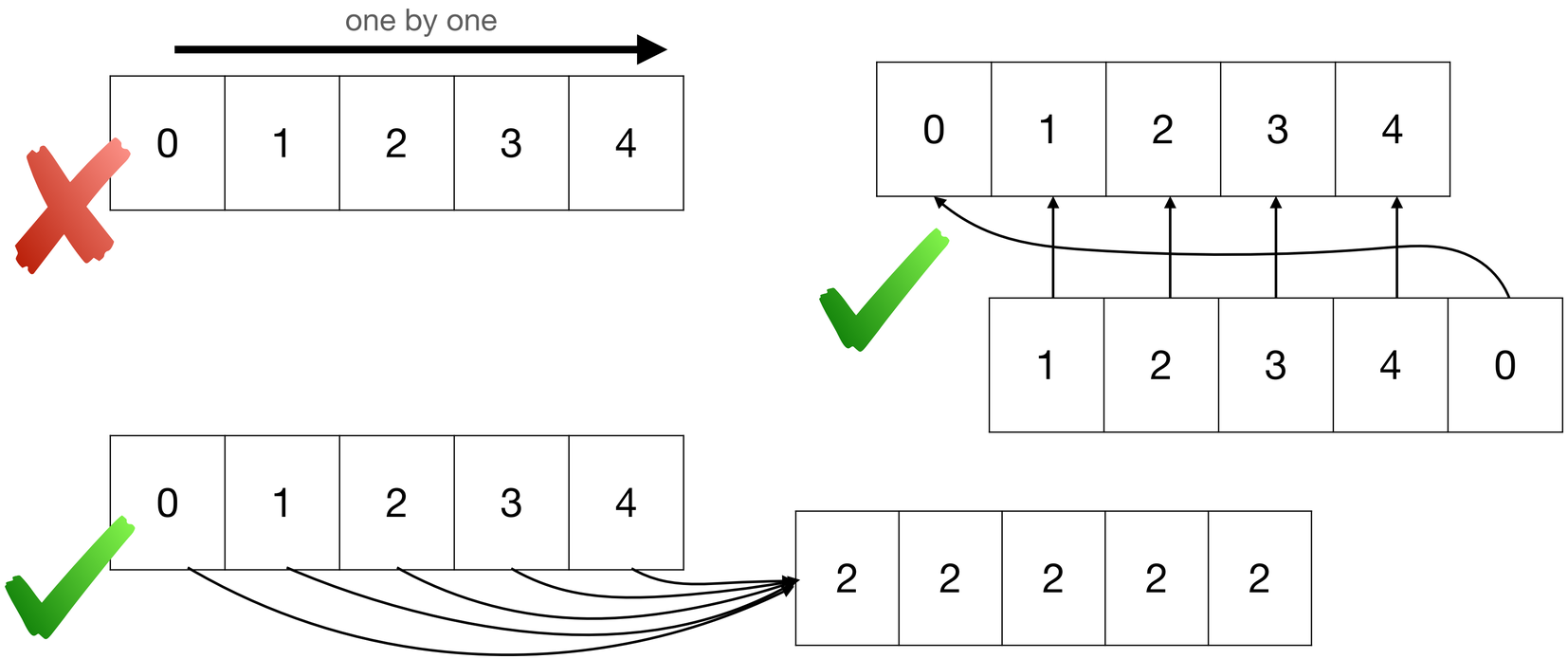

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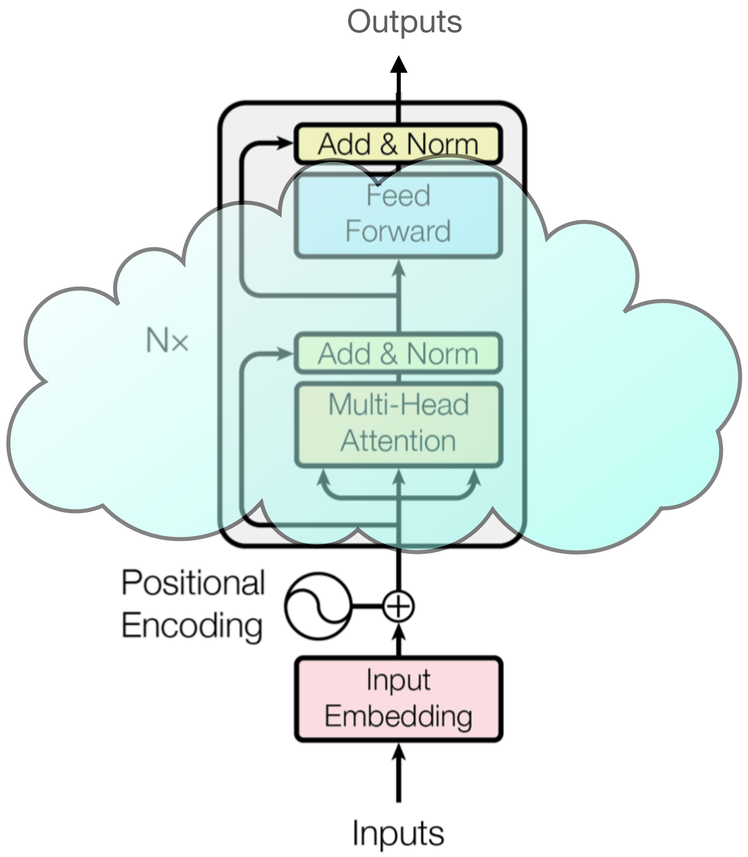

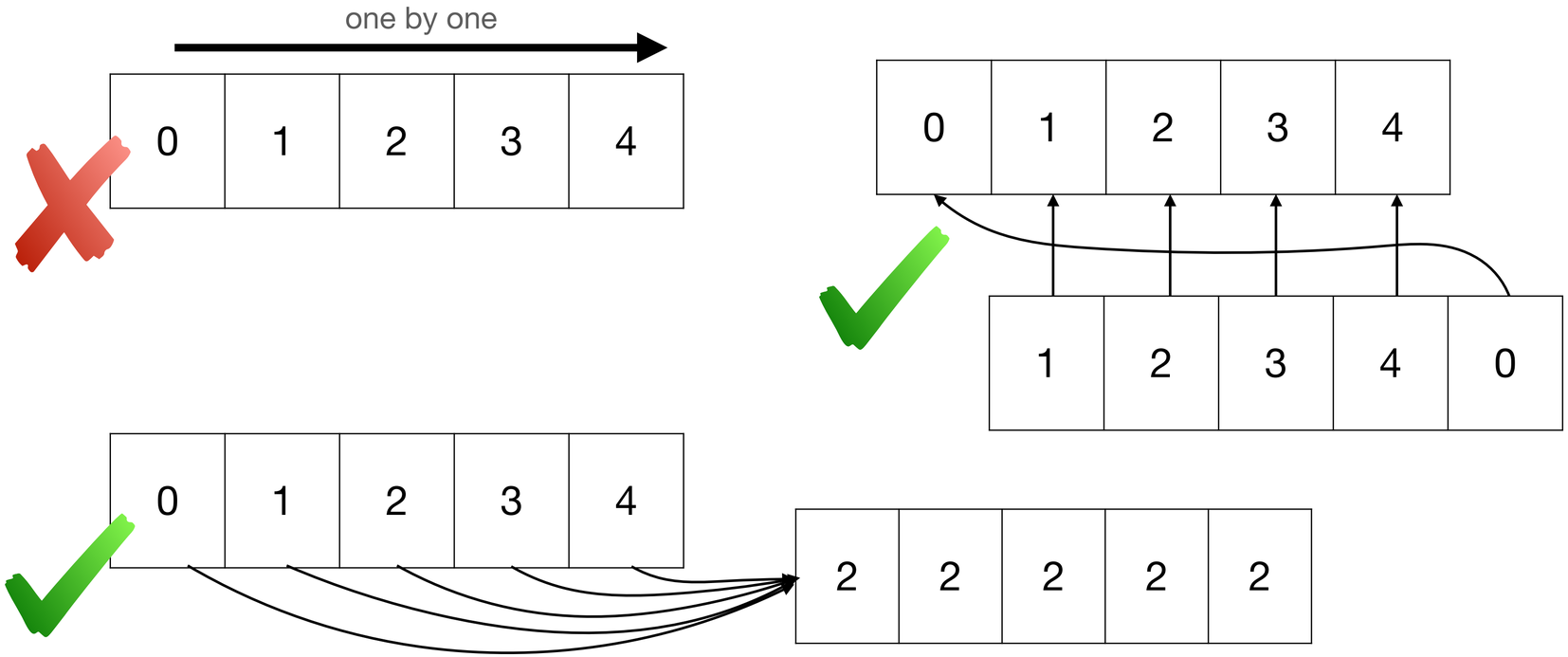

Symbolic:

"A" 😀

instead of

[0.1,-0.2,0.65,…???] ☹️

RASP

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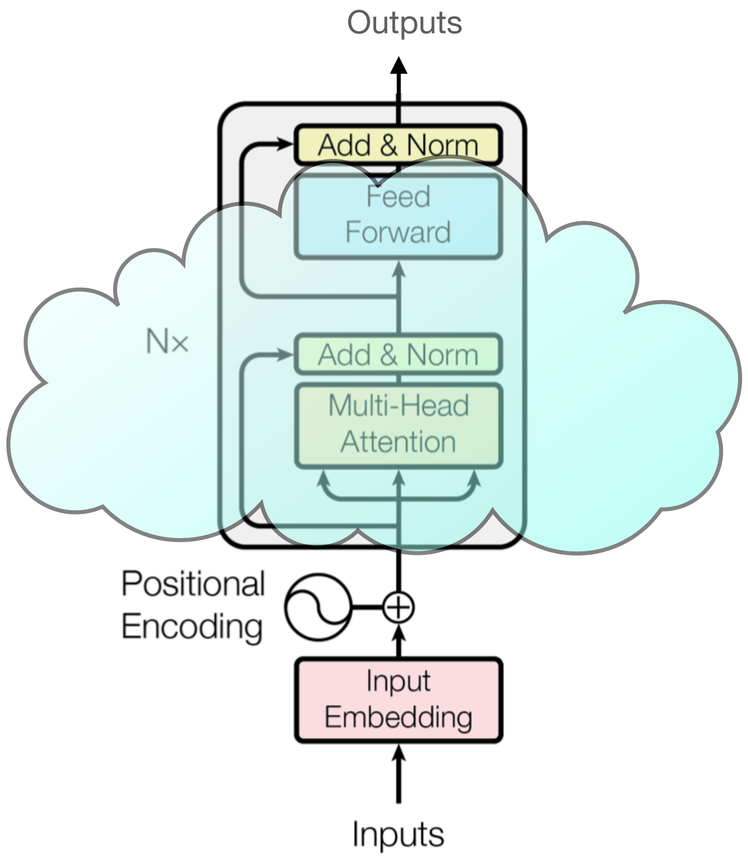

Primitive Sequences:

tokens = [R,A,S,P]

indices = [0,1,2,3]

length = [4,4,4,4]

RASP

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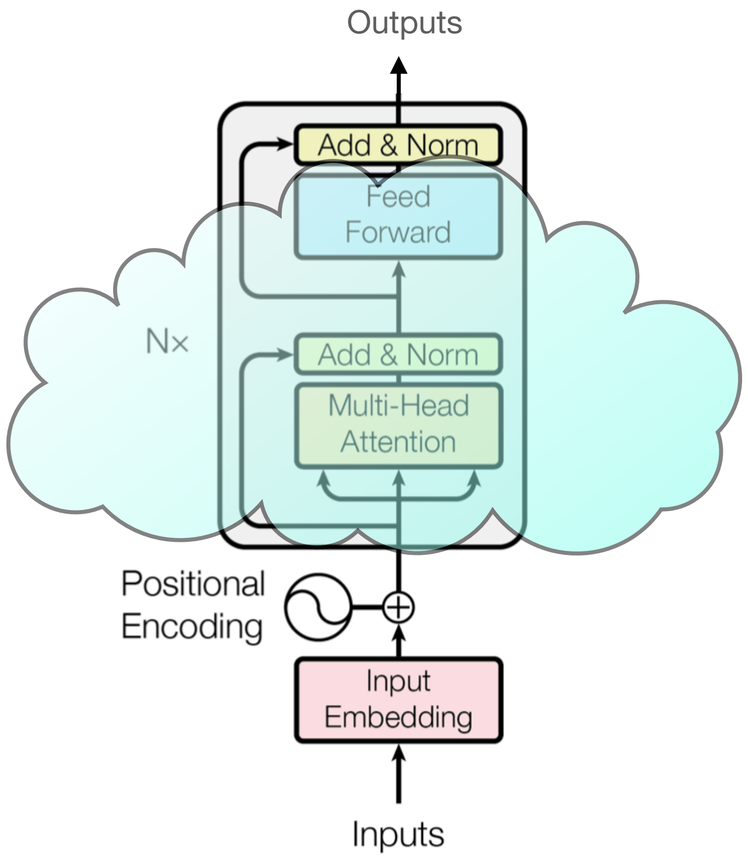

Primitive Sequences:

tokens = [R,A,S,P]

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Elementwise Operations:

indices*2 = [0,2,4,6]

indices+length = [4,5,6,7]

...

RASP

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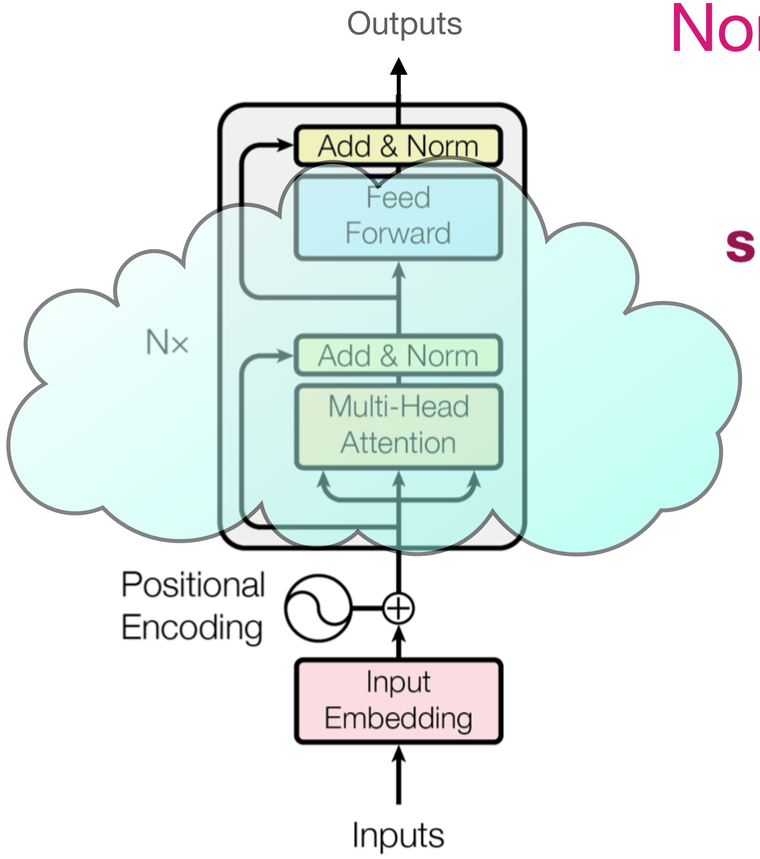

Non-Elementwise Operations:

s = select([1,2,2],[0,1,2],==) **res=aggregate(s, [4,6,8])**

	1	2	2
0	F	F	F
1	T	F	F
2	F	T	T

			4	6	8				
F	F	F	4	6	8	=>	0		
T	F	F	4	6	8	=>	4	=>	[0,4,7]
F	T	T	4	6	8	=>	7		

RASP

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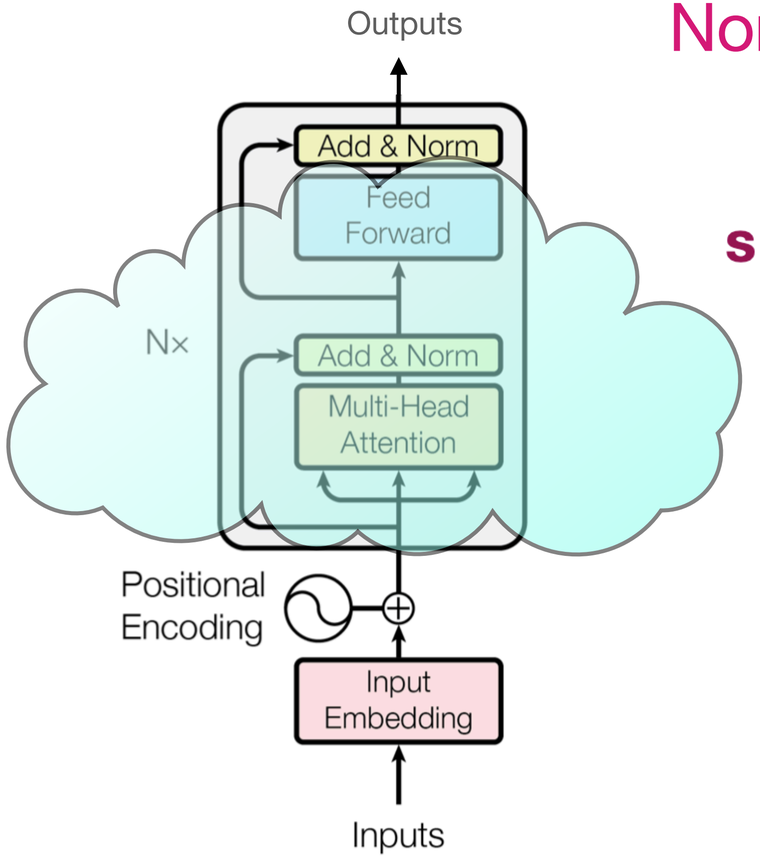

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	1	2	2
0	F	F	F
1	**T**	F	F
2	F	**T**	**T**

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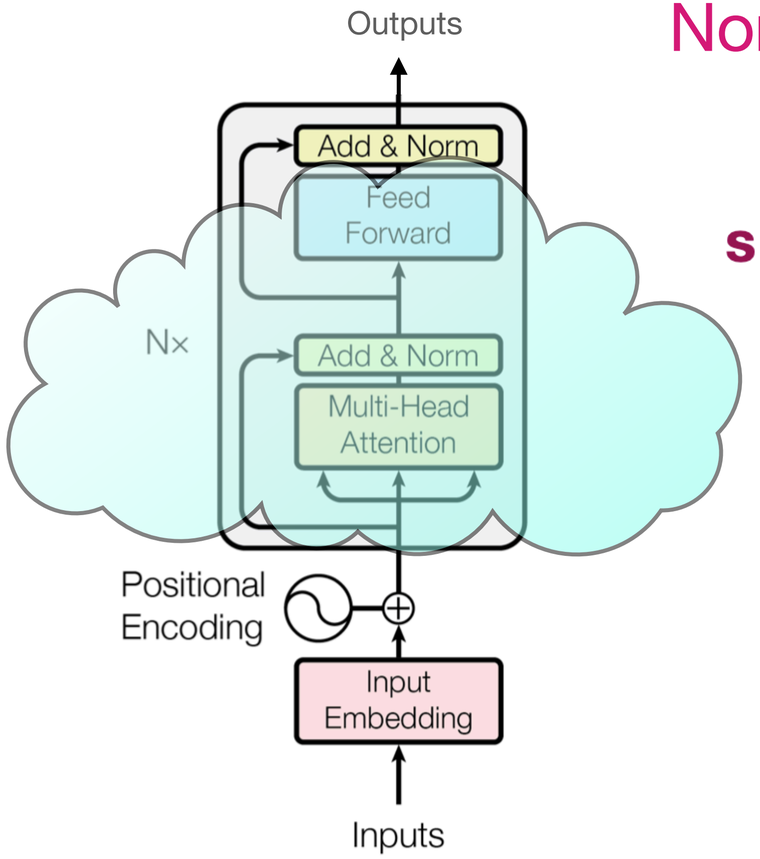

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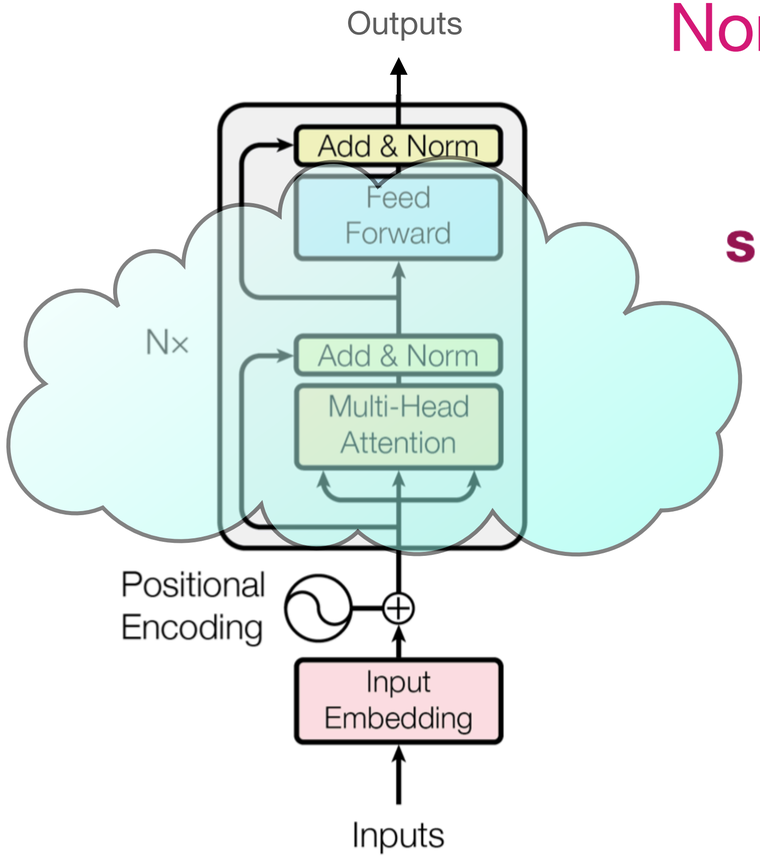

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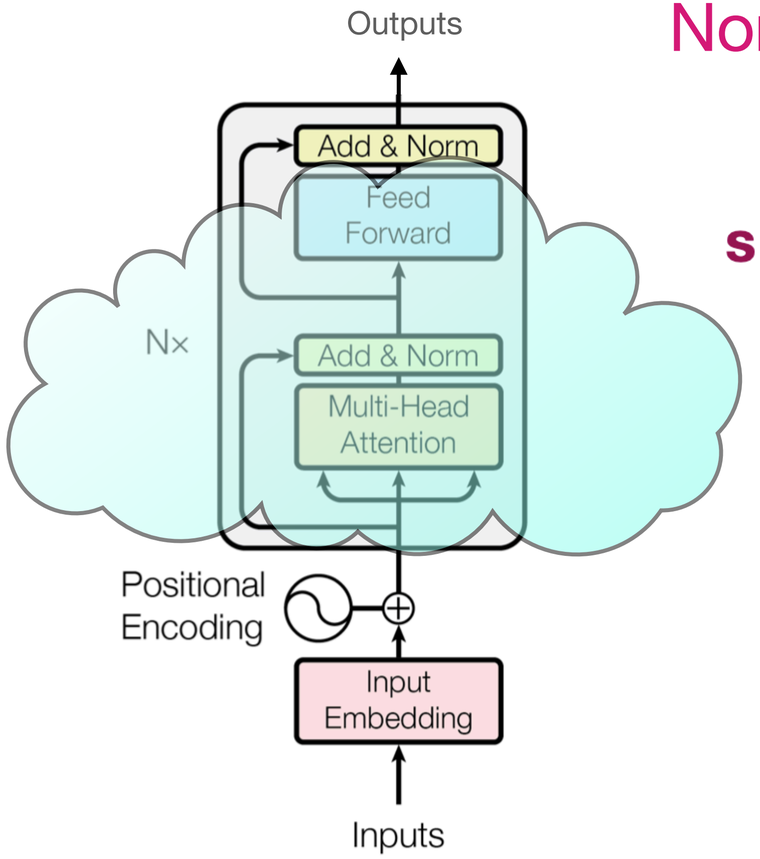

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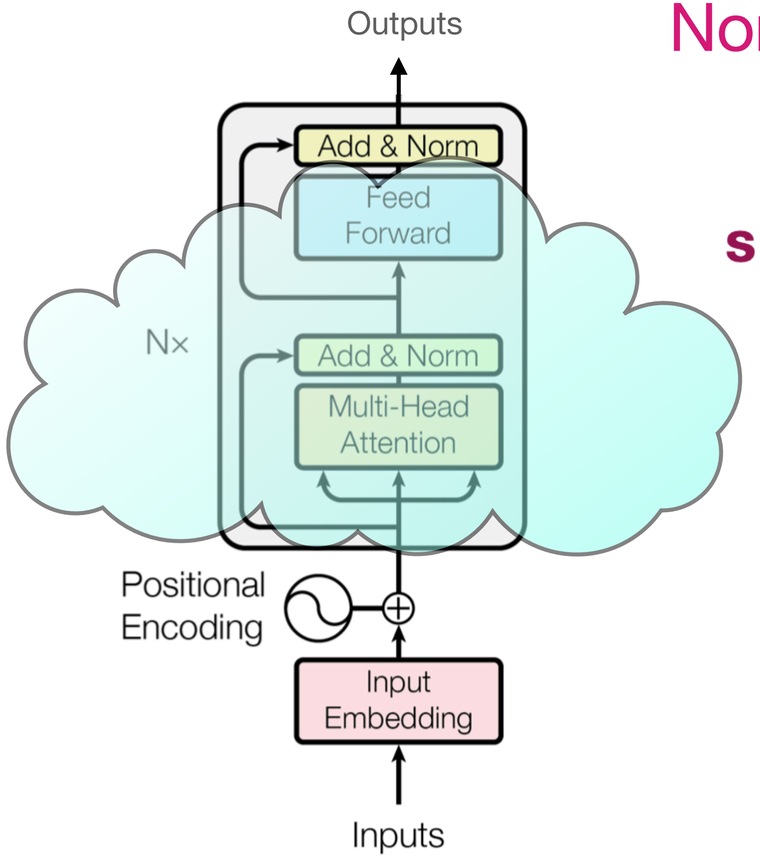

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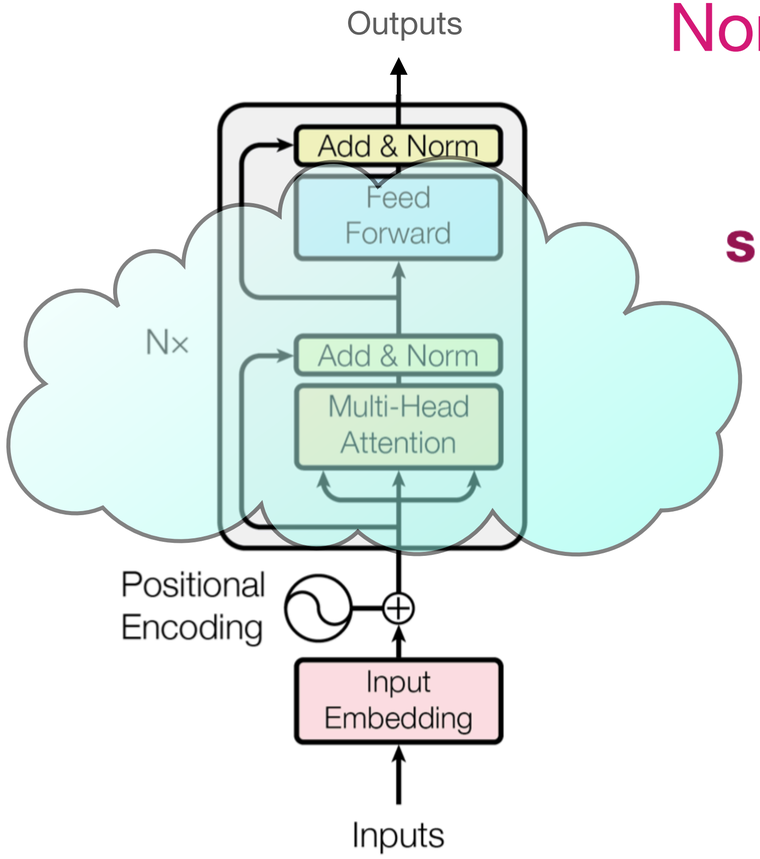

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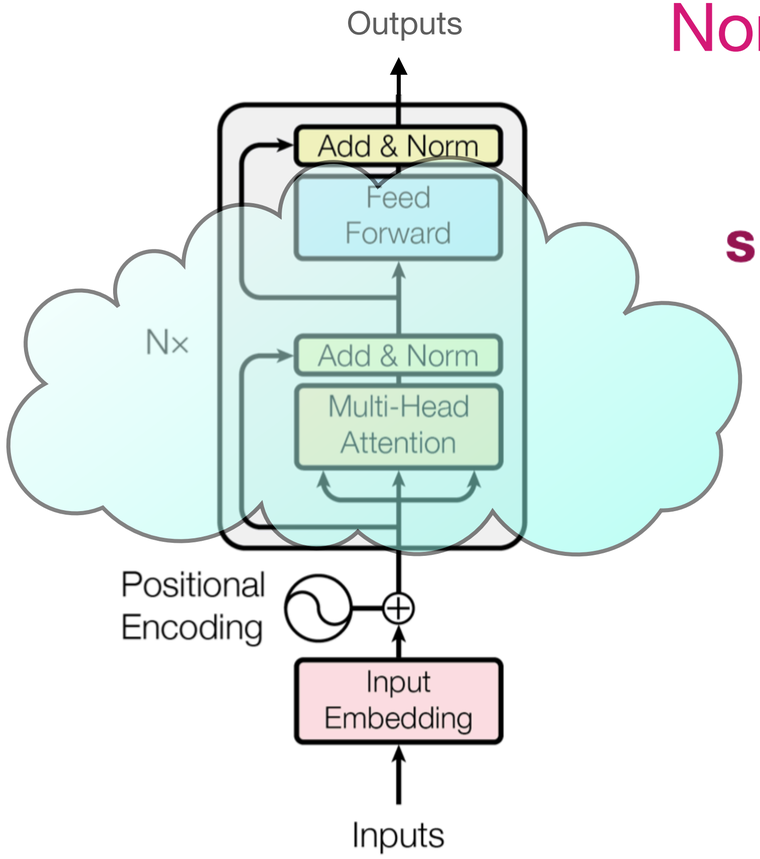

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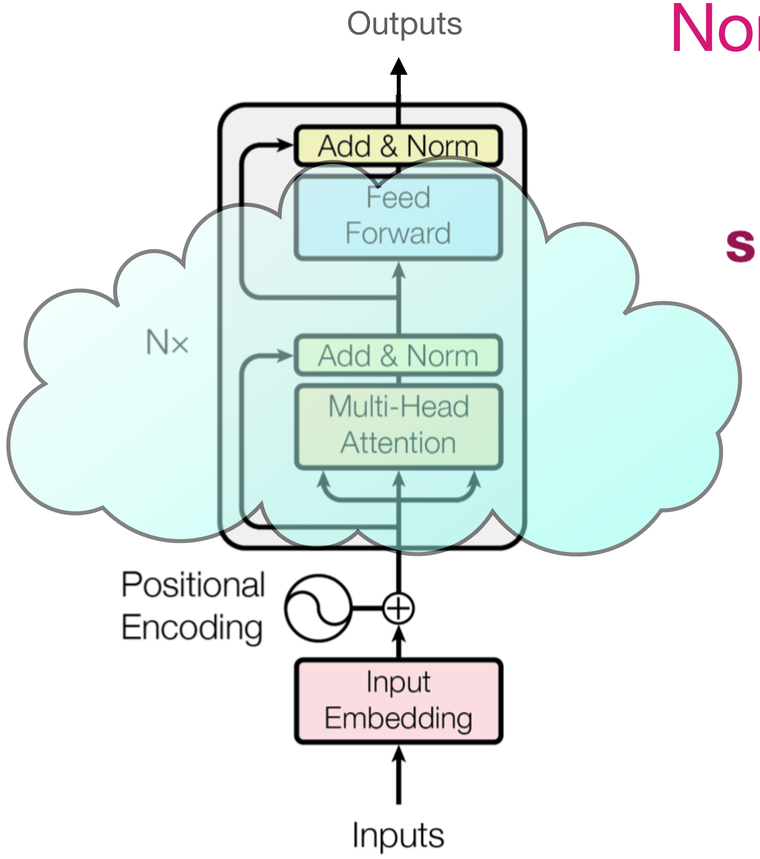
RASP

Restricted Access Sequence Processing



Non-Elementwise Operations:

s = select([1,2,2],[0,1,2],==) **res=aggregate(s, [4,6,8])**

	1	2	2
0	F	F	F
1	T	F	F
2	F	T	T

			4	6	8				
F	F	F	4	6	8	=>	0		
T	F	F	4	6	8	=>	4	=>	[0,4,7]
F	T	T	4	6	8	=>	7		

RASP

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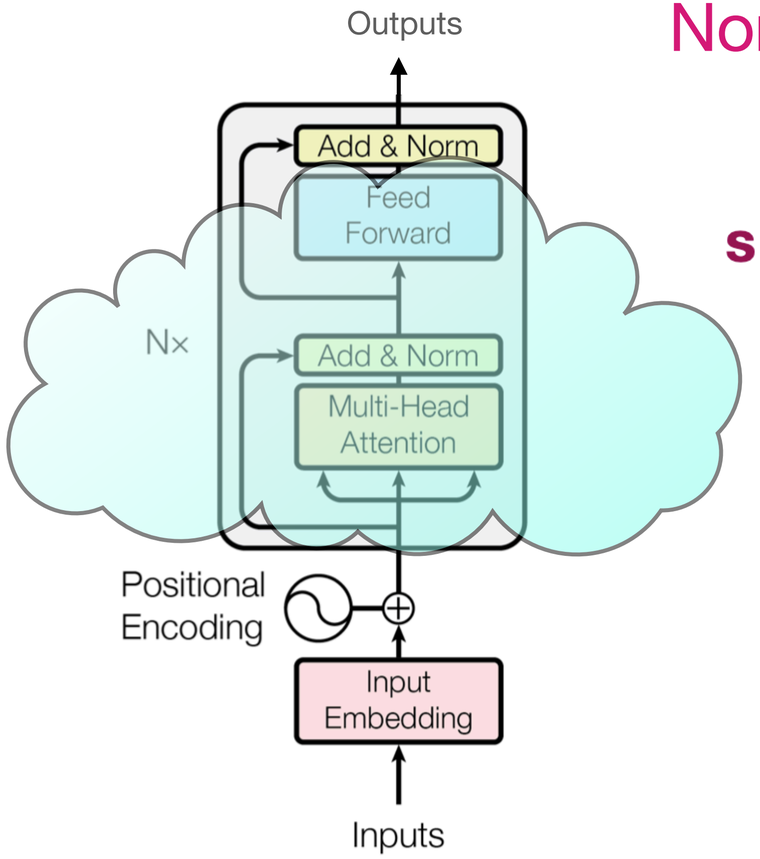

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RASP

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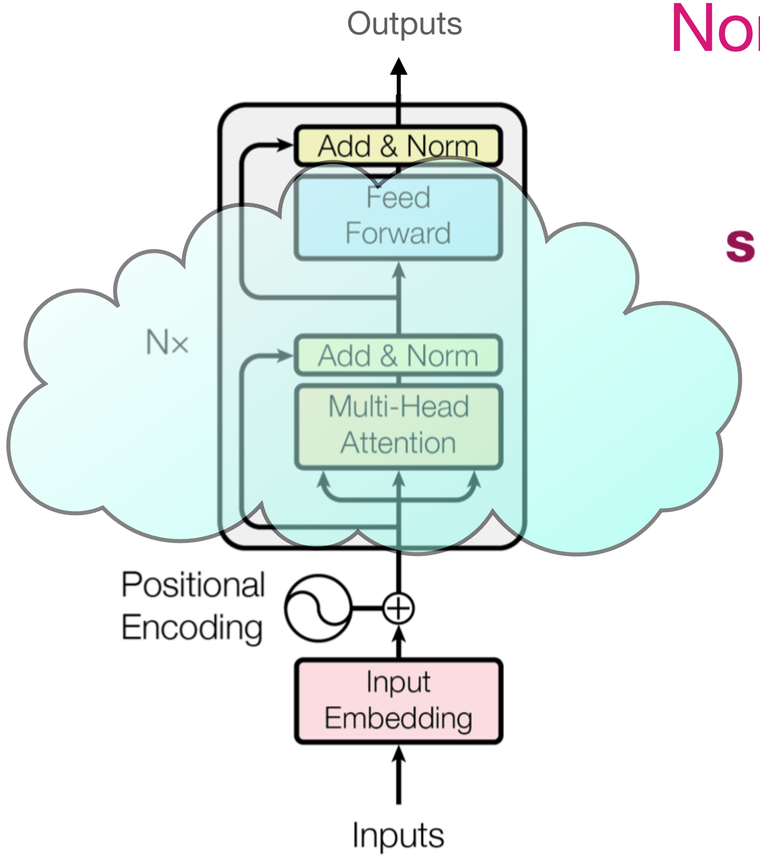

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RASP

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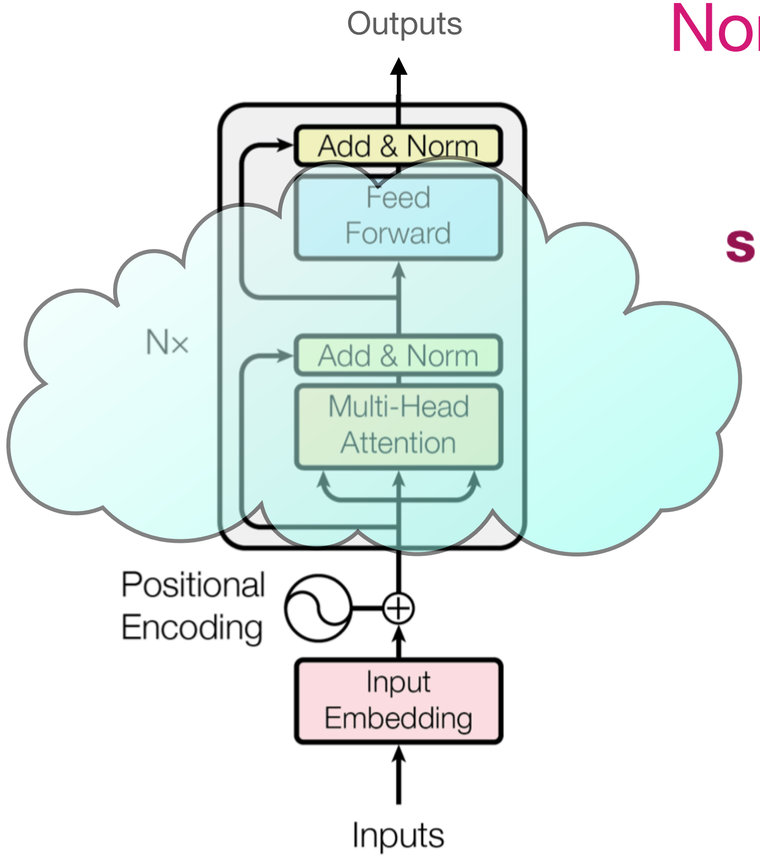

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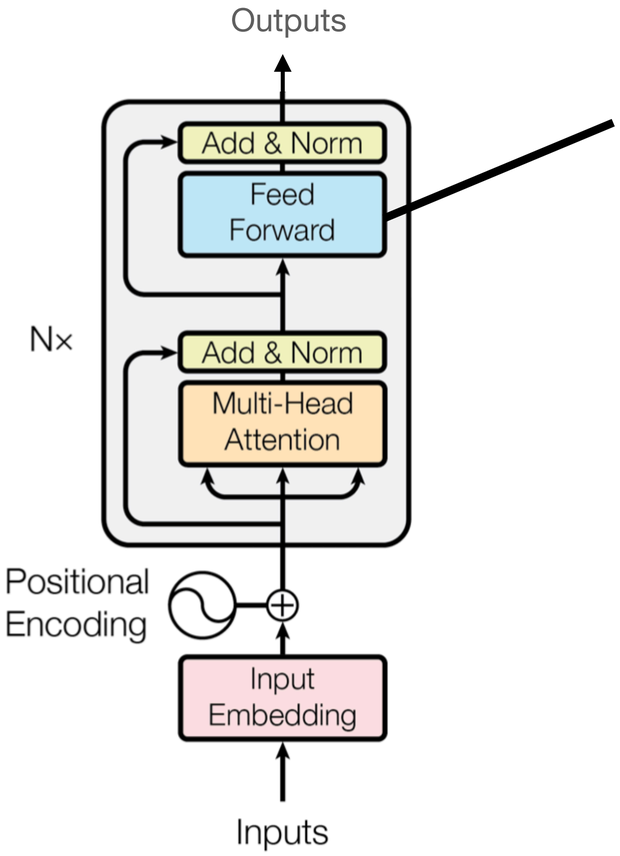
=> **[0,4,7]**

RASP

Restricted Access Sequence Processing



Feed Forward Sublayer

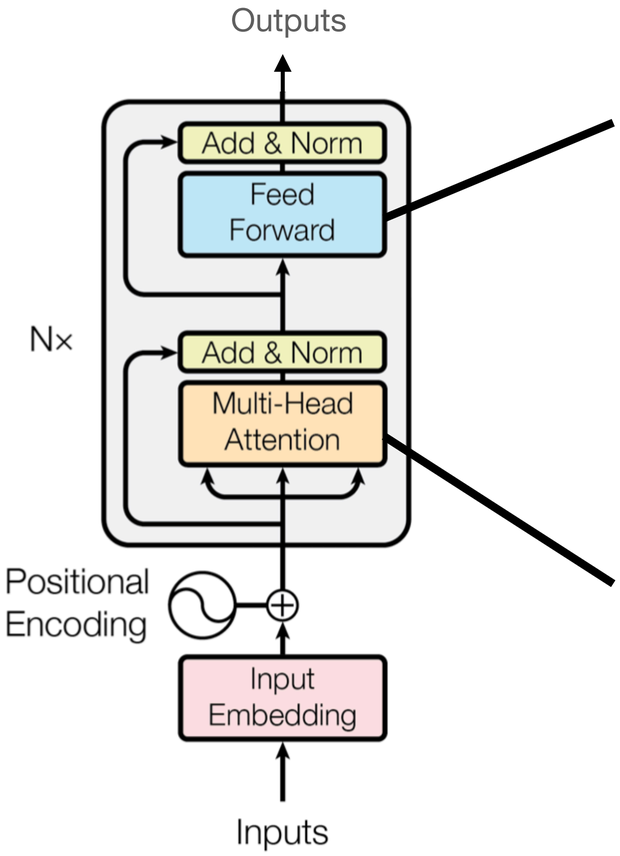
indices*2 = [0,2,4,6]

indices+length = [4,5,6,7]

...

RASP

Restricted Access Sequence Processing



Feed Forward Sublayer

Attention Head

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F	F	F	4	6	8	=>	0	
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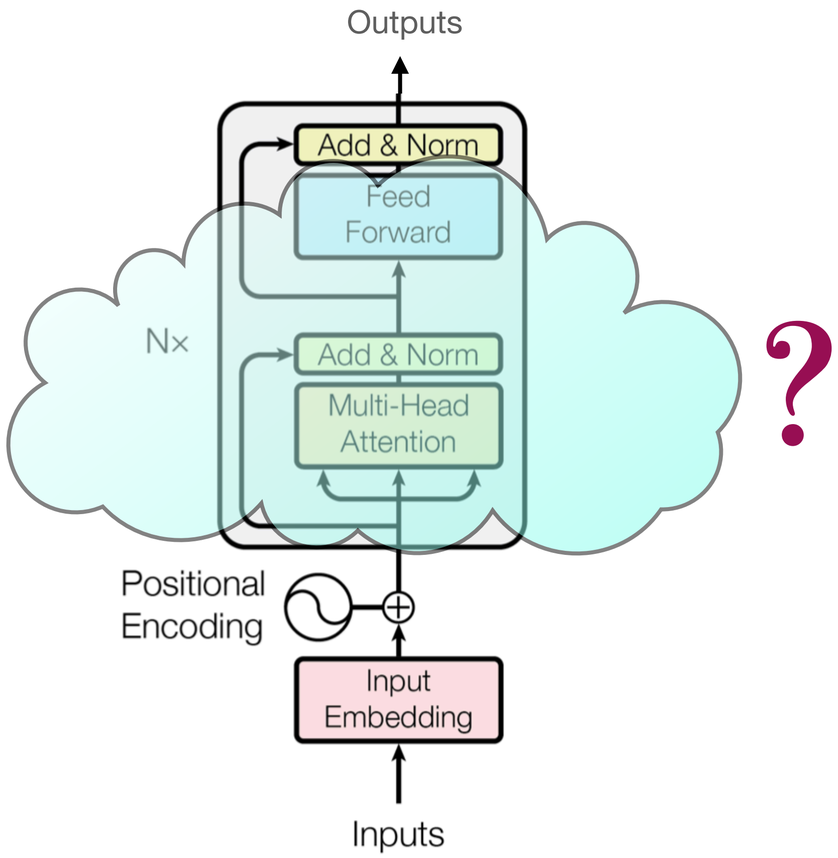
F	T	T	4	6	8	=>	7	

Can it solve “Reverse”?

abcde ↦ edcba

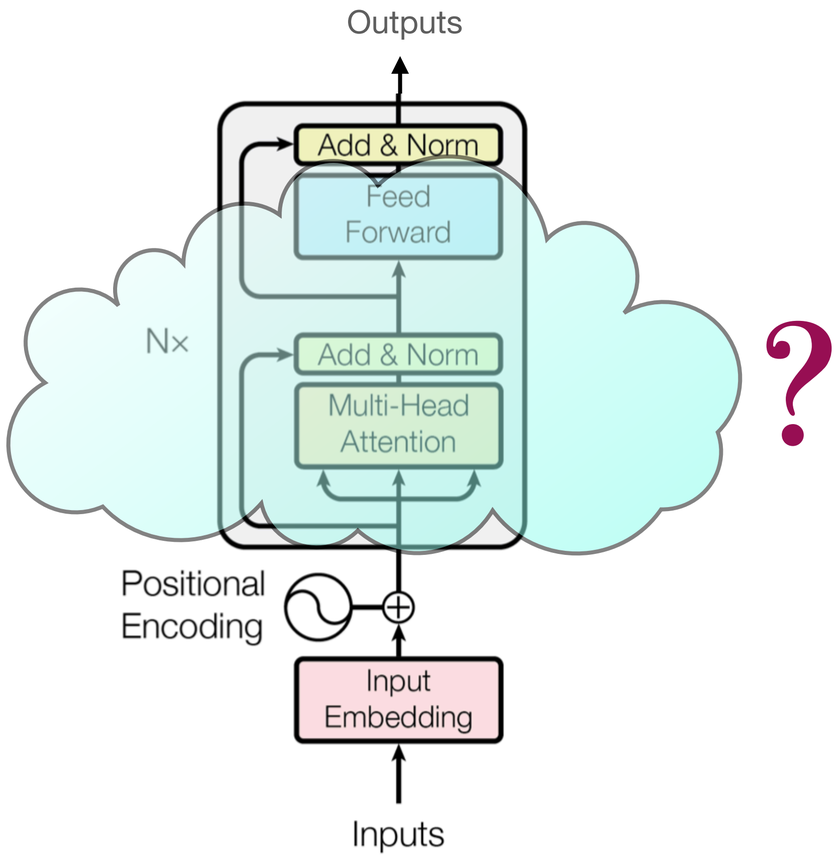


?

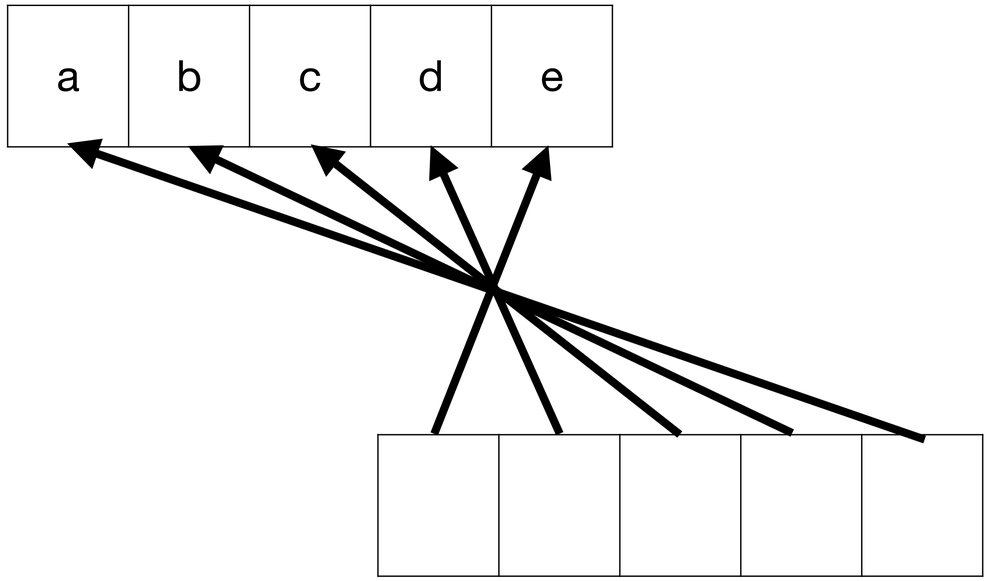
a	b	c	d	e

Can it solve “Reverse”?

abcde ↦ edcba



?



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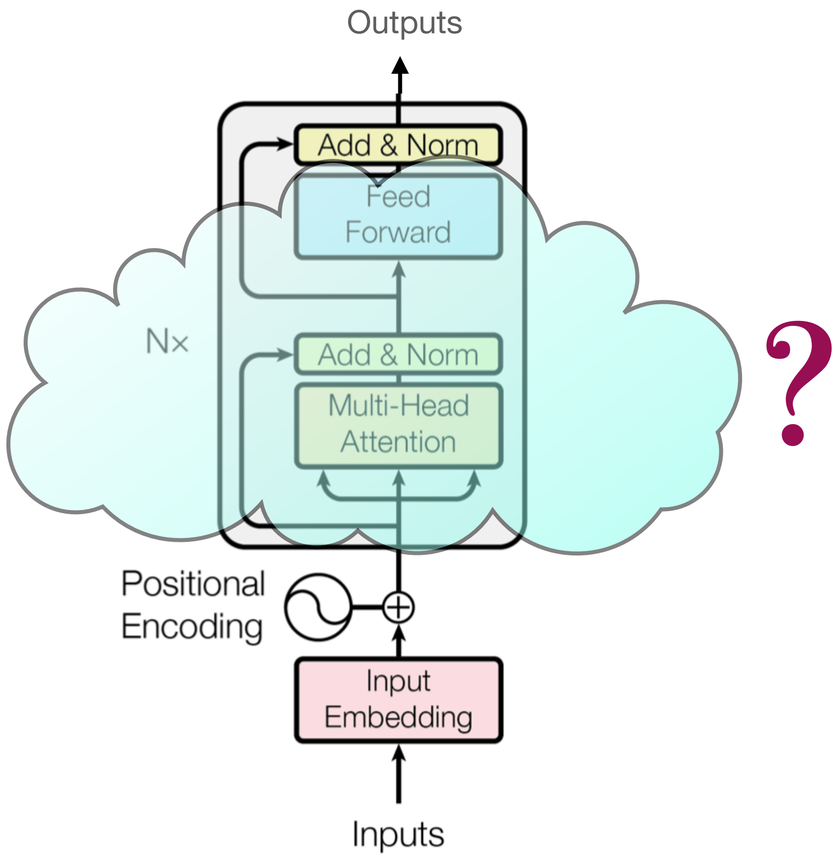

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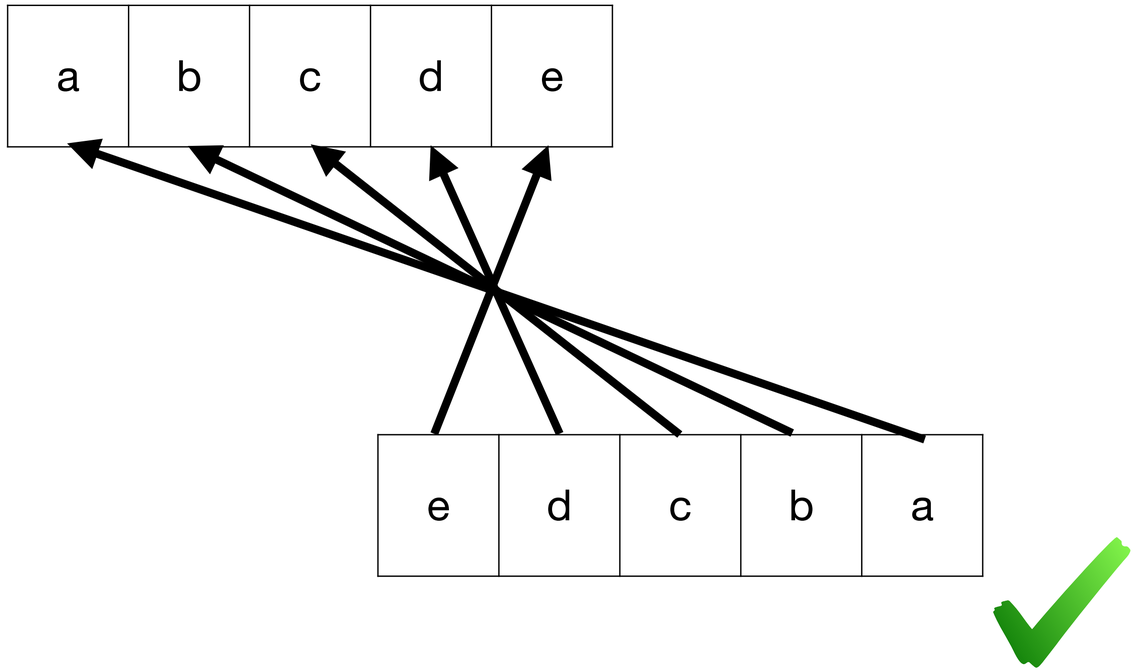
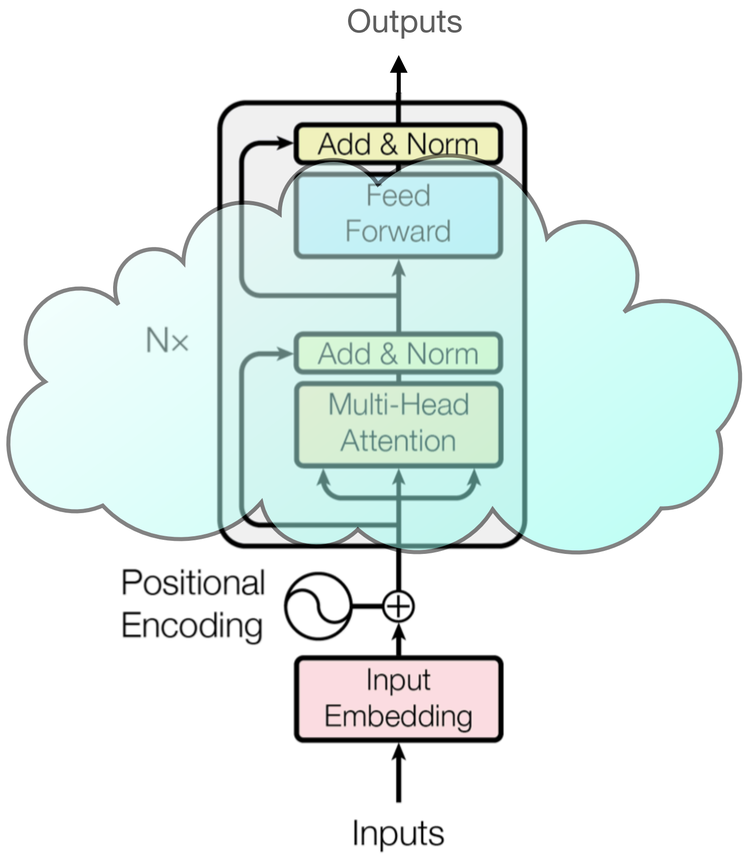


RASP

Restricted Access Sequence Processing

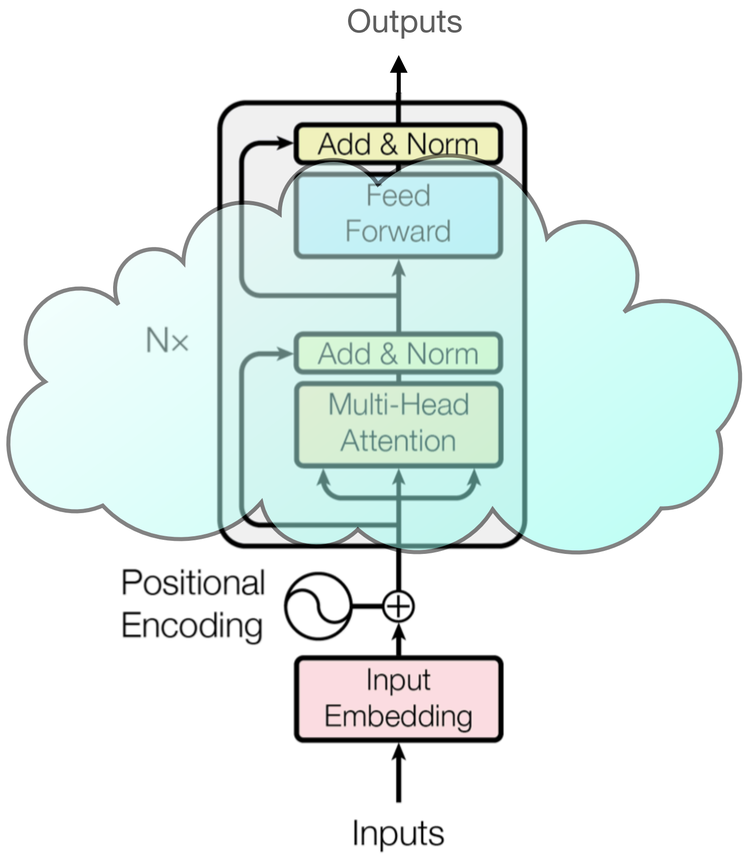
```
target = length-indices-1;
```
= [3,2,1,0]



RASP

Restricted Access Sequence Processing

```
target = length-indices-1;
flip = select(target,indices,==);
```



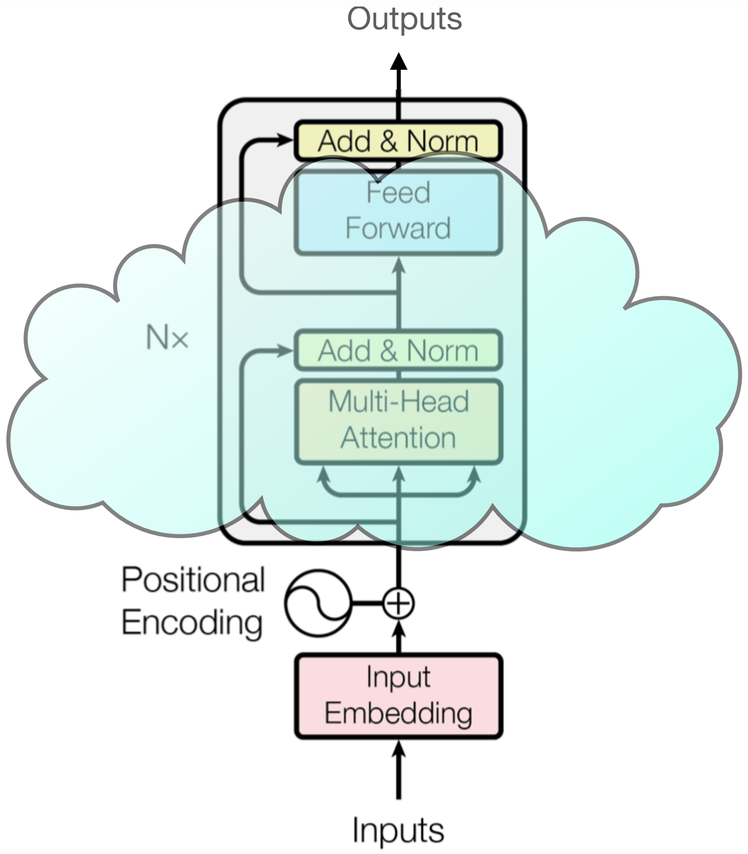
flip = select([3,2,1,0],[0,1,2,3],==)

	3	2	1	0
0	F	F	F	T
1	F	F	T	F
2	F	T	F	F
3	T	F	F	F

RASP

Restricted Access Sequence Processing

```
target = length-indices-1;
flip = select(target,indices,==);
reverse = aggregate(flip,tokens);
```



reverse=aggregate(flip, [R,A,S,P])

```
          R A S P
F F F T   R A S P  =>  P
F F T F   R A S P  =>  S  =>  [P,S,A,R]
F T F F   R A S P  =>  A
T F F F   R A S P  =>  R
```

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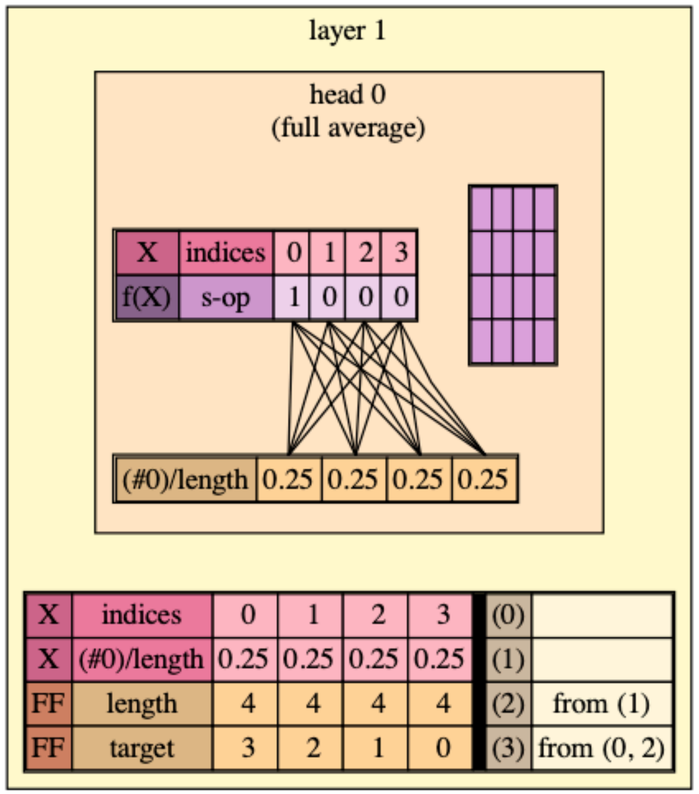

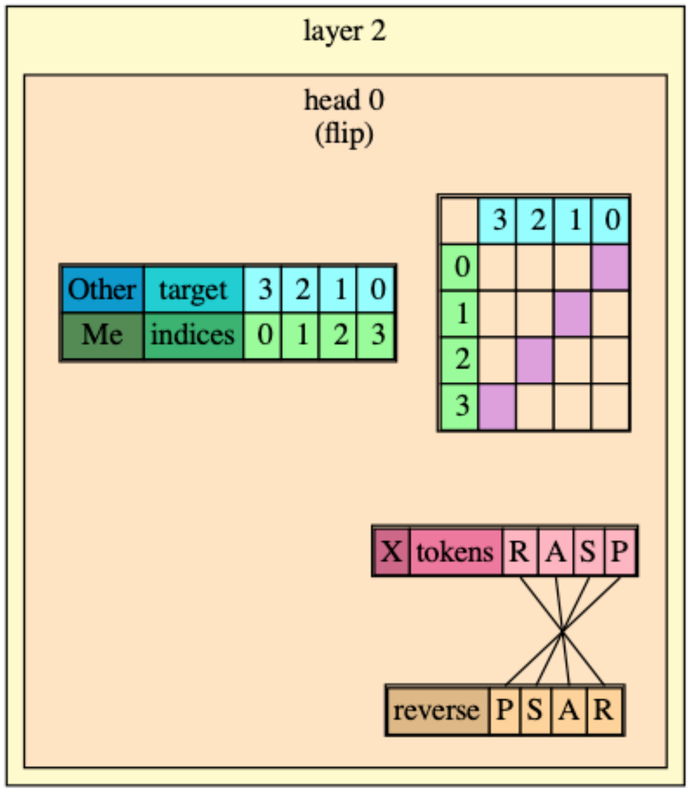

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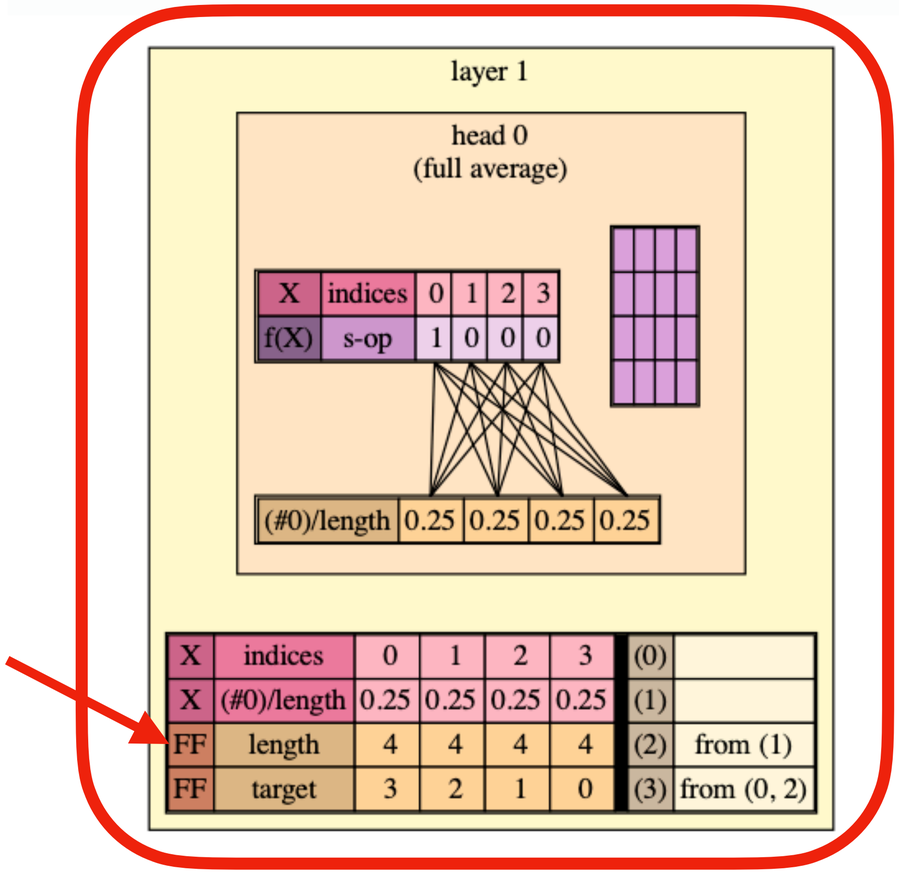

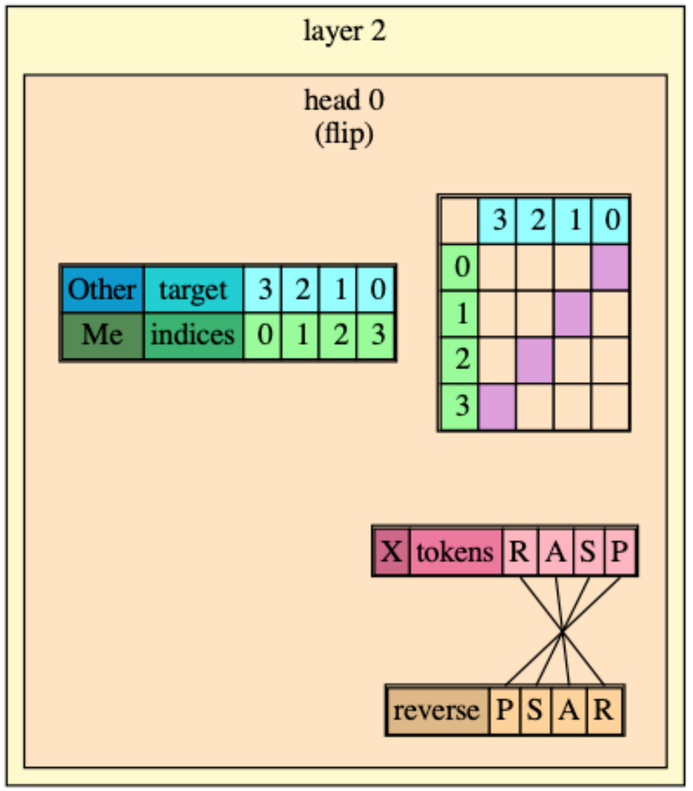

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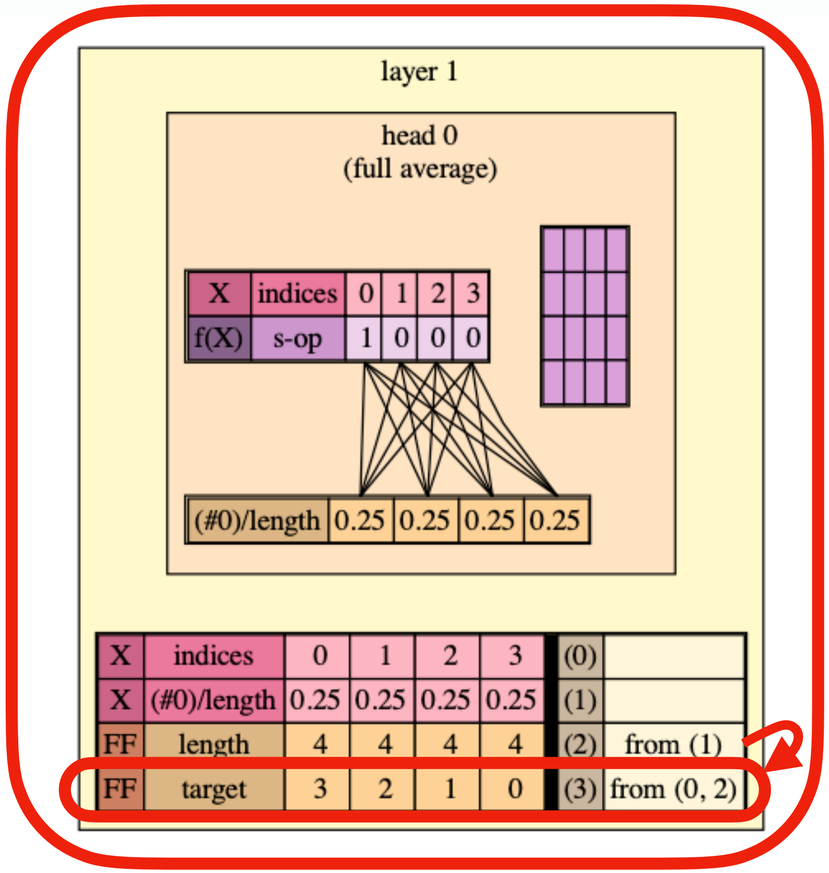

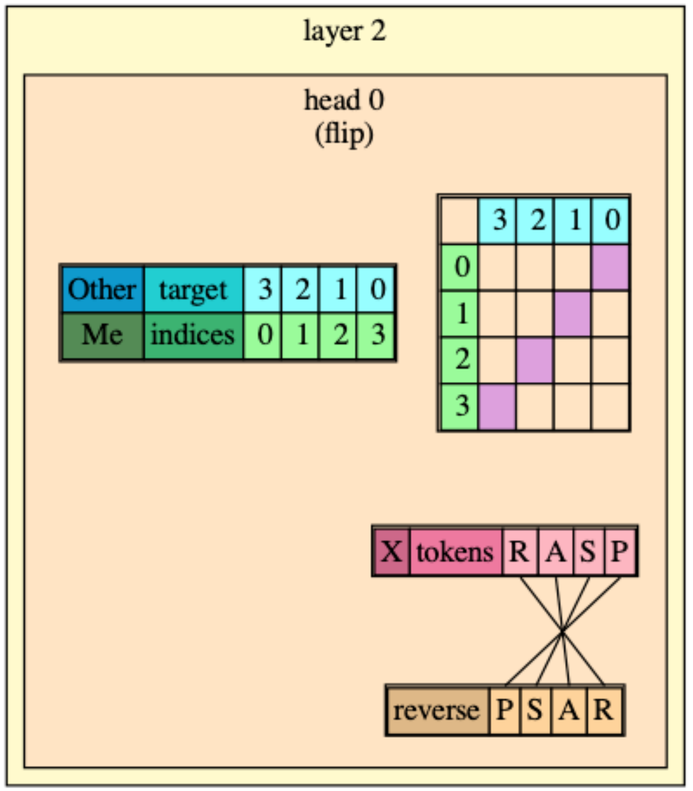

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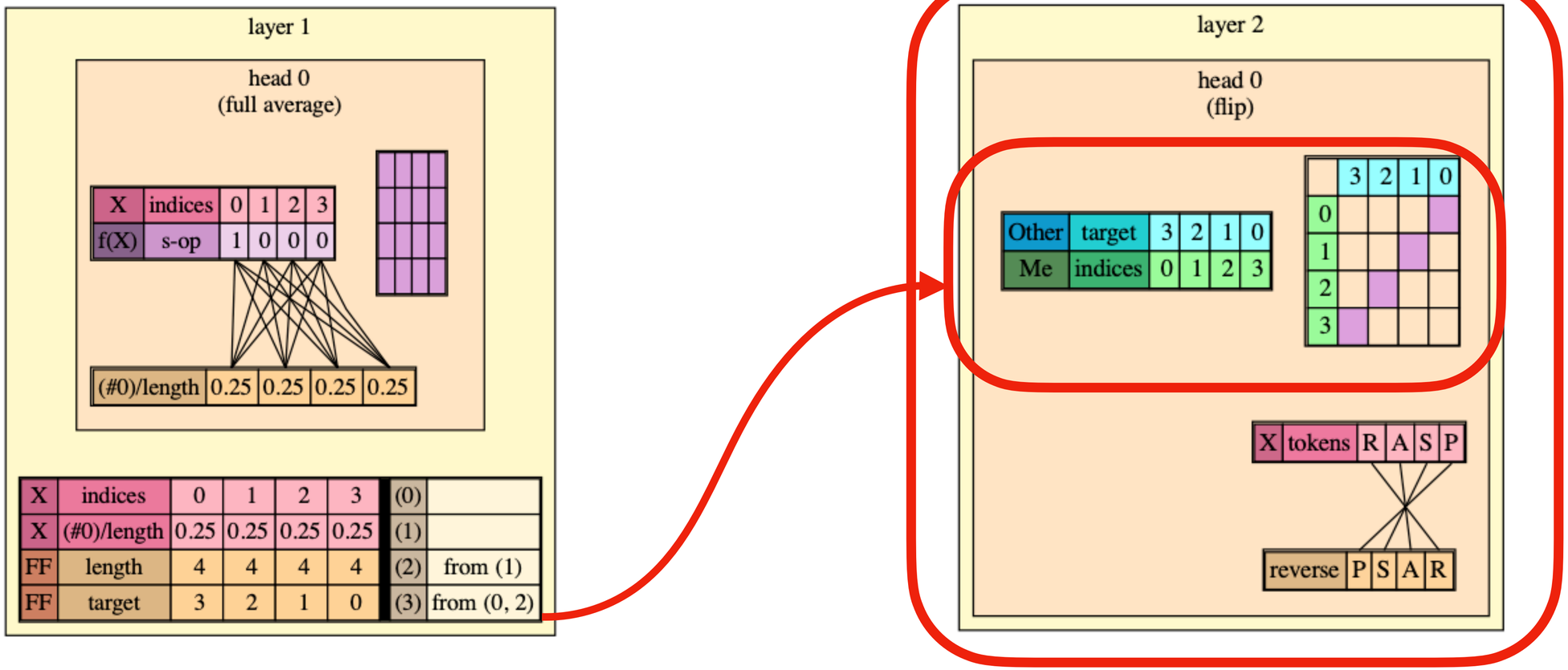

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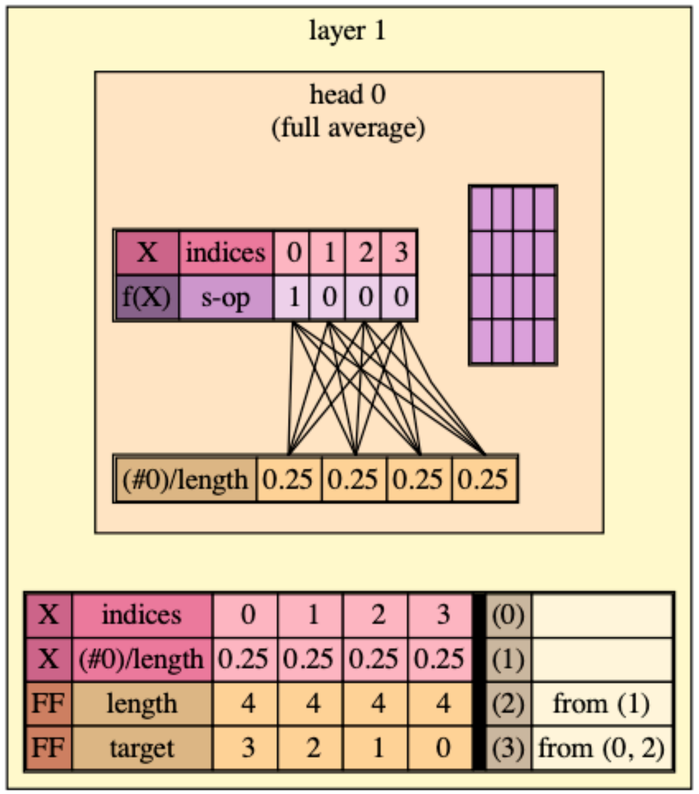

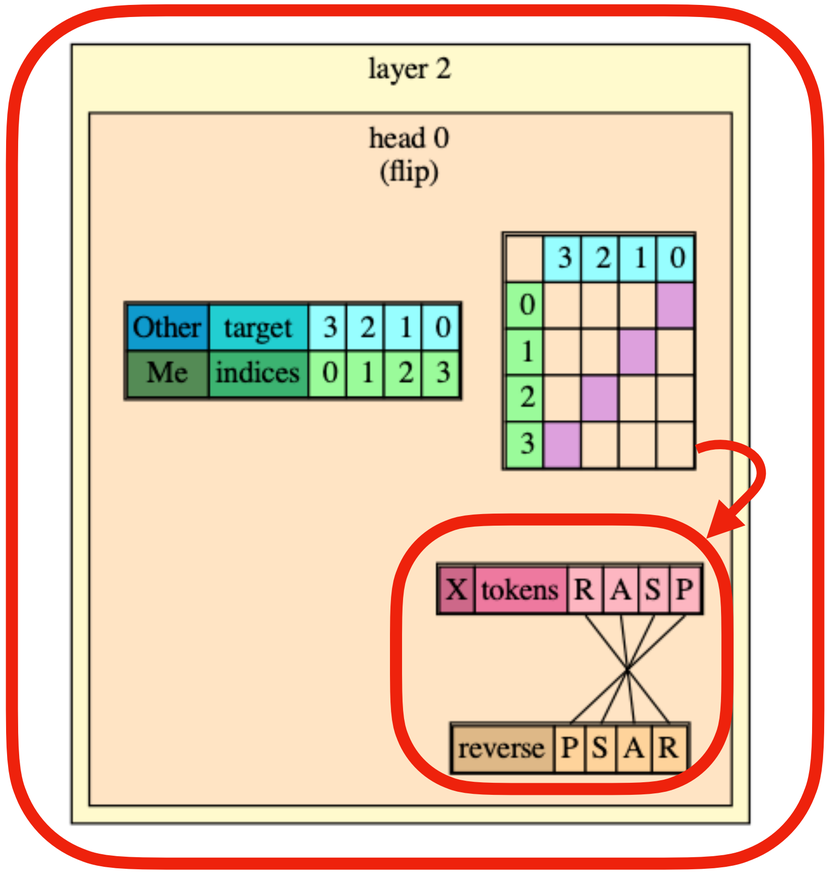

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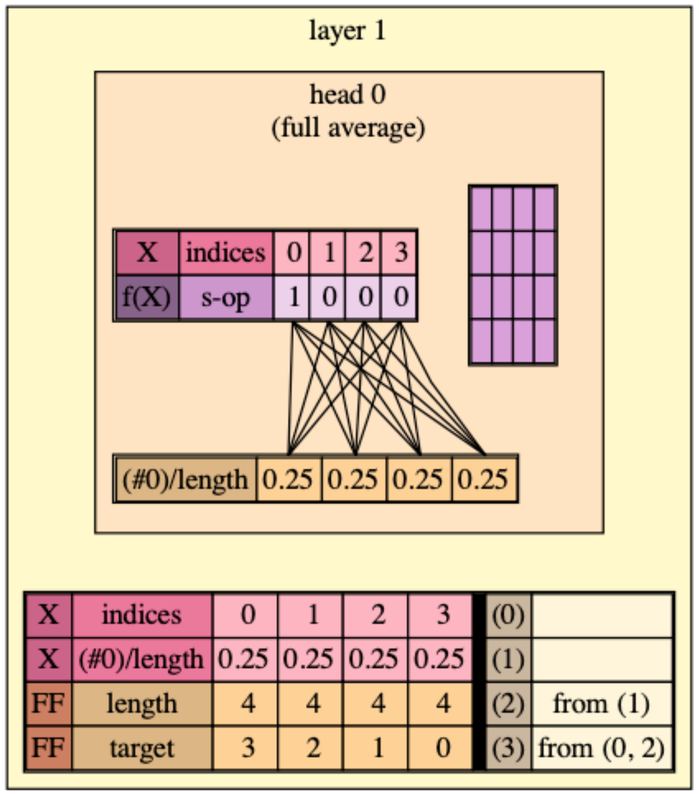

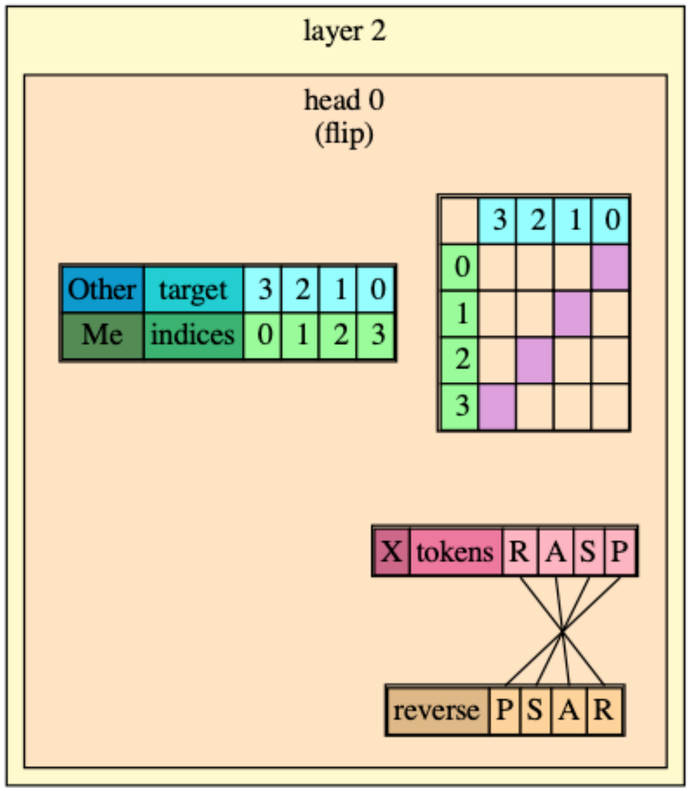

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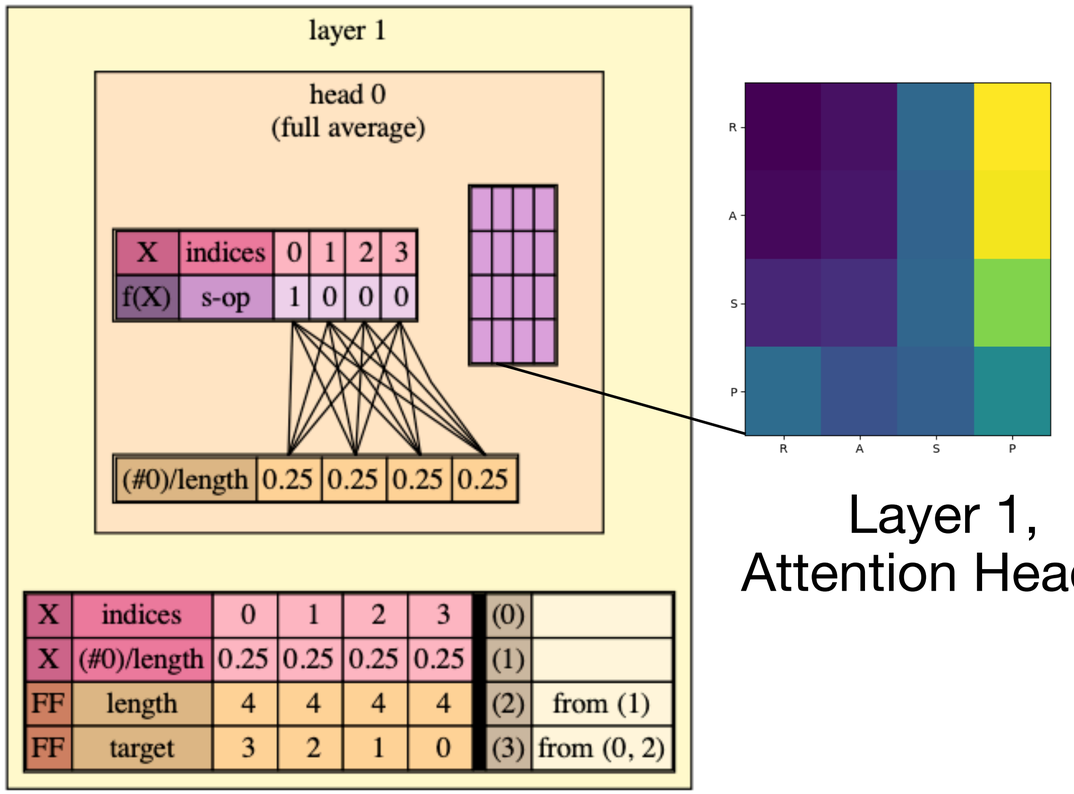
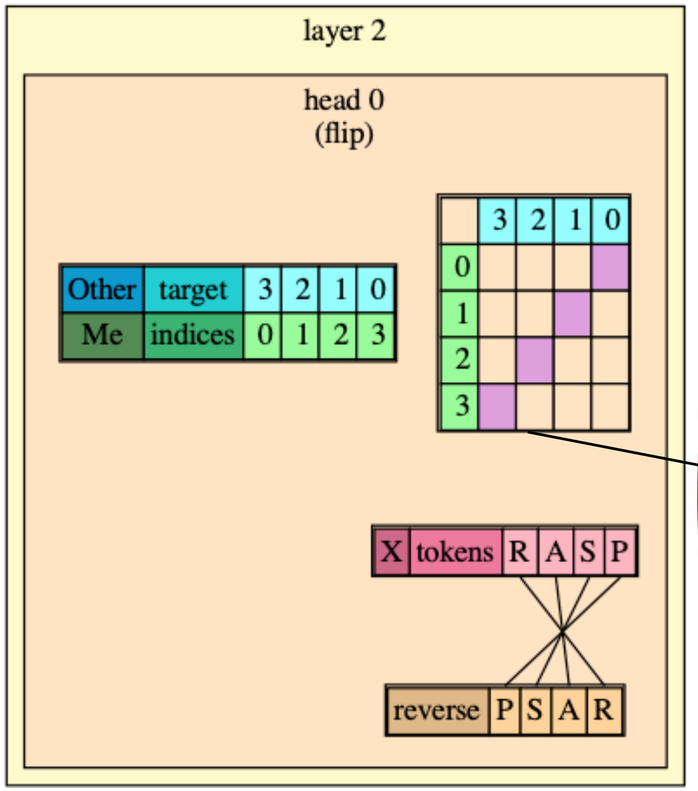
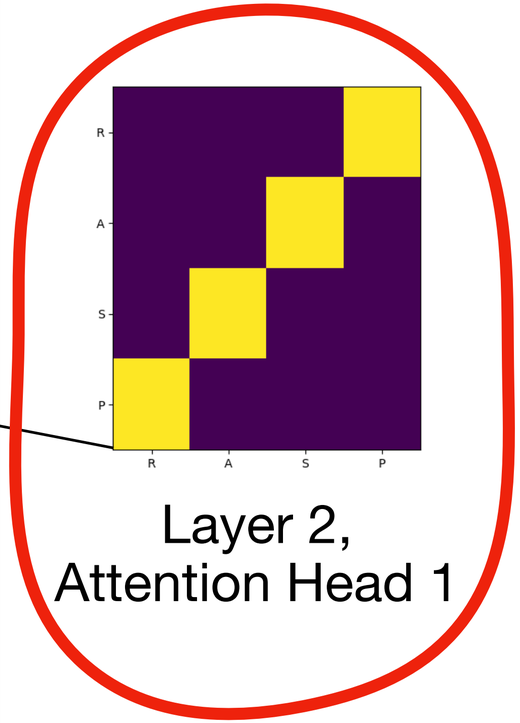


Layer 1,
Attention Head 1





Layer 2,
Attention Head 1

Conclusion

Try it out!! :

github.com/tech-srl/RASP

- RASP: abstraction for transformer-encoder
- Solve formal tasks in transformer-encoders
  - Even Dyck-k for arbitrary k and unbounded depth!
- Translate to neural transformer-encoders architectures
  - Exact weights still required

More details in paper!