

Transformer Model (1/2): **Attention without RNN**

Shusen Wang

Transformer Model

- **Original paper:** Vaswani et al. [Attention Is All You Need](#). In *NIPS*, 2017.

Attention Is All You Need

Ashish Vaswani*
Google Brain
avaswani@google.com

Noam Shazeer*
Google Brain
noam@google.com

Niki Parmar*
Google Research
nikip@google.com

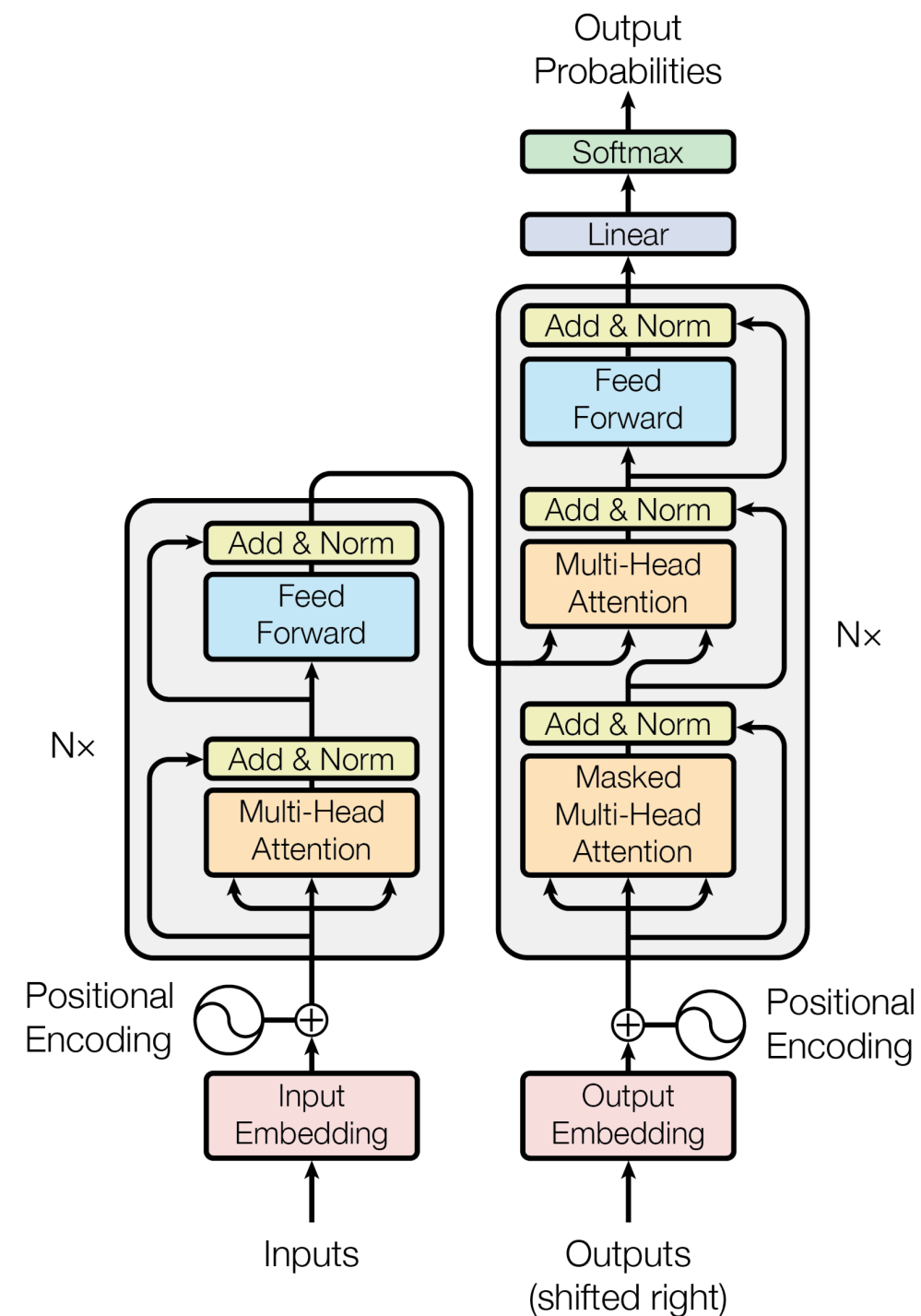
Jakob Uszkoreit*
Google Research
usz@google.com

Llion Jones*
Google Research
llion@google.com

Aidan N. Gomez* †
University of Toronto
aidan@cs.toronto.edu

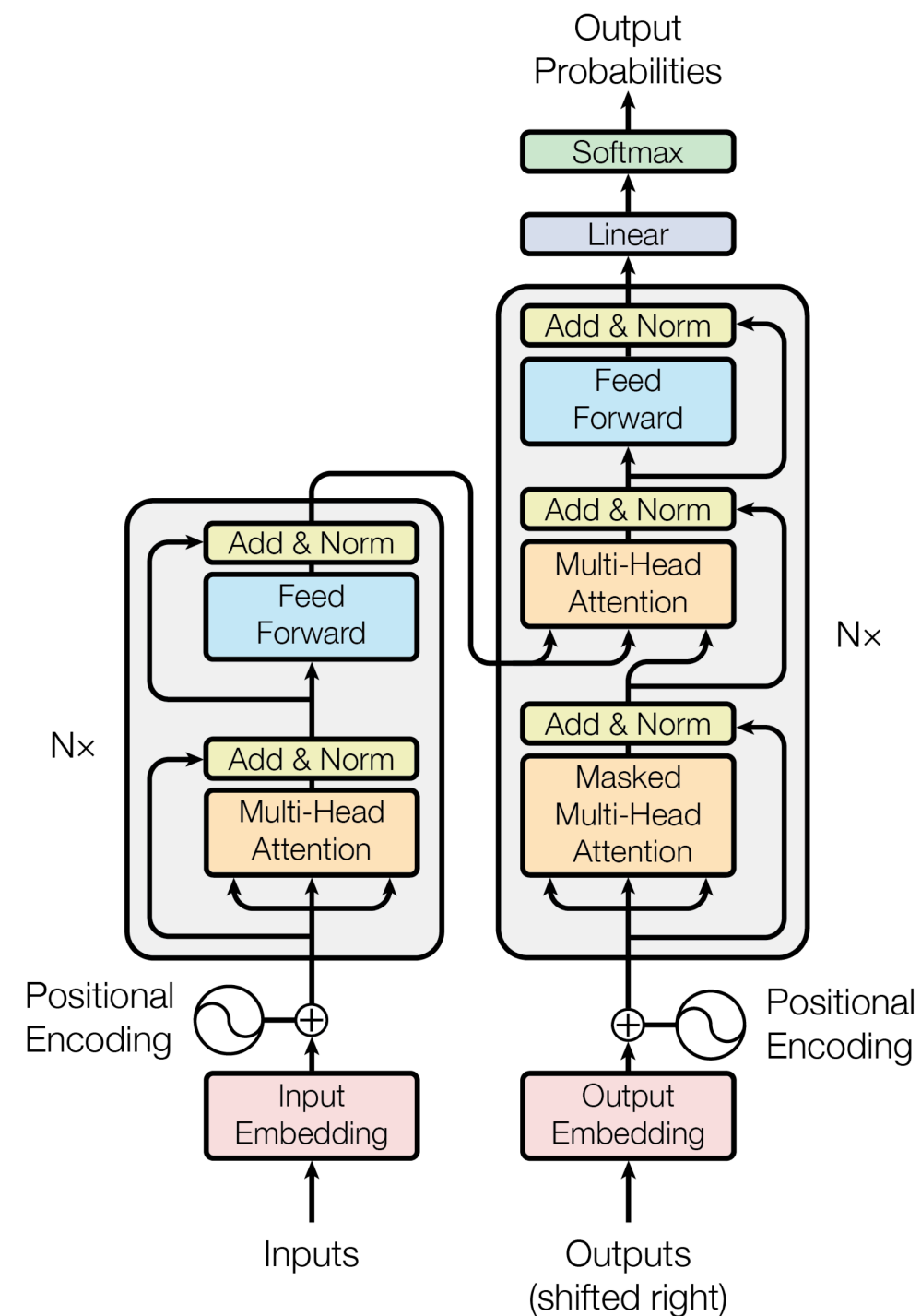
Łukasz Kaiser*
Google Brain
lukaszkaizer@google.com

Illia Polosukhin* ‡
illia.polosukhin@gmail.com



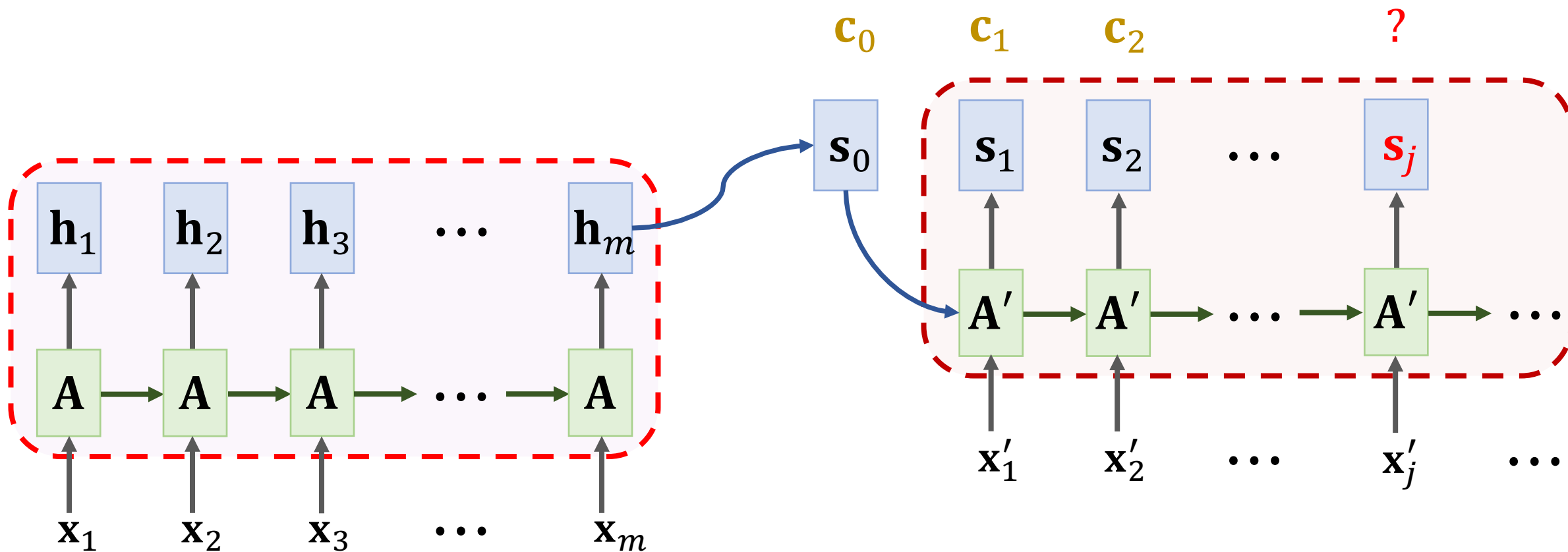
Transformer Model

- Transformer is a Seq2Seq model.
- Transformer is not RNN.
- Purely based attention and dense layers.
- Higher accuracy than RNNs on large datasets.



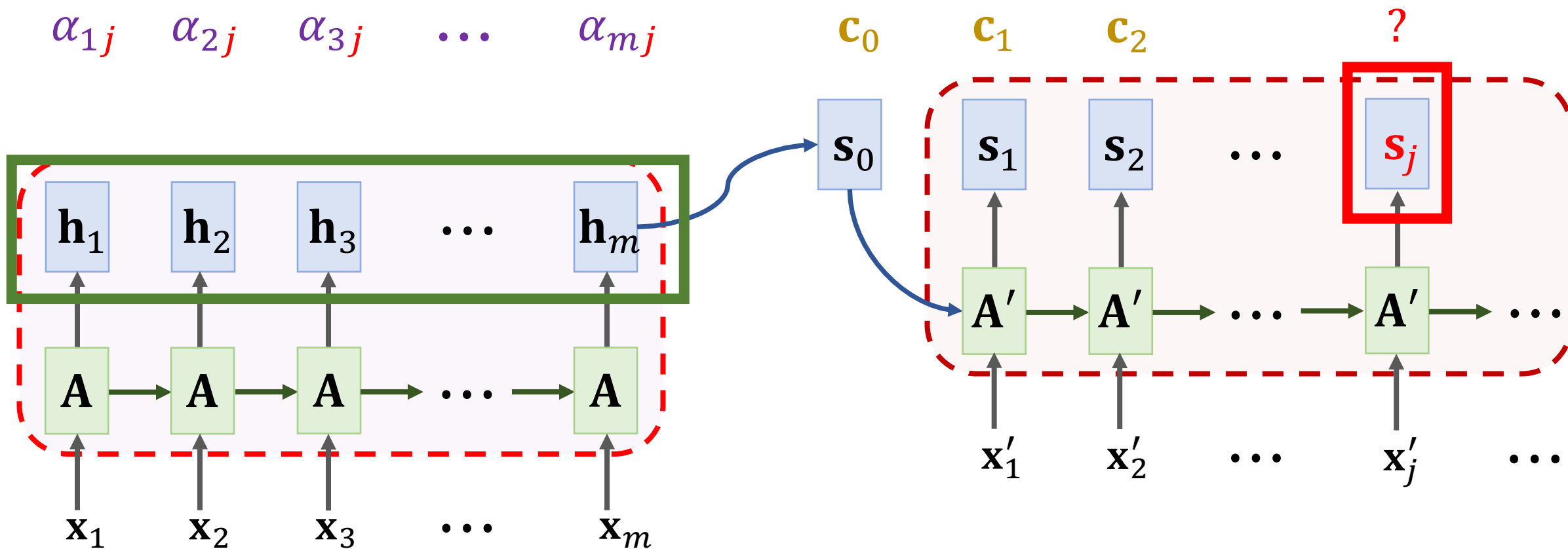
Revisiting **Attention** for RNN

Attention for Seq2Seq Model



Attention for Seq2Seq Model

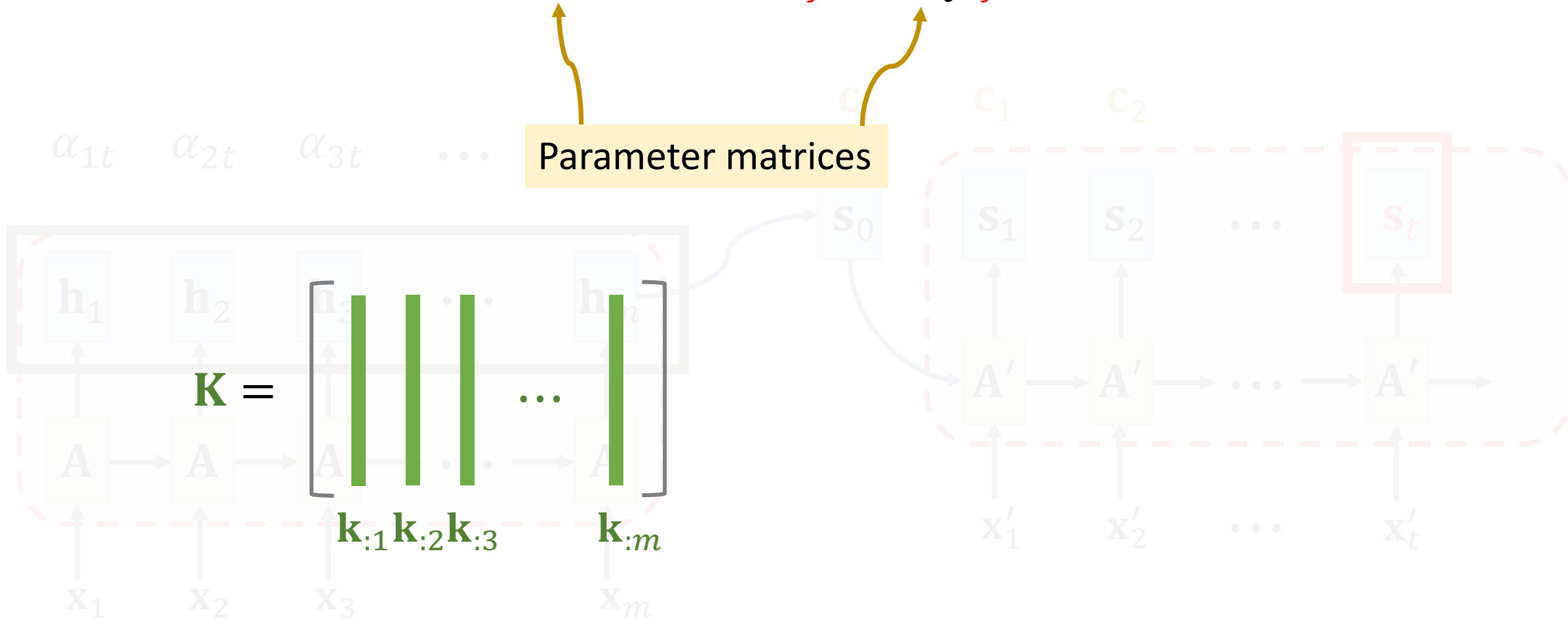
Weights: $\alpha_{ij} = \text{align}(\mathbf{h}_i, \mathbf{s}_j)$.



Attention for Seq2Seq Model

Weights: $\alpha_{ij} = \text{align}(\mathbf{h}_i, \mathbf{s}_j)$.

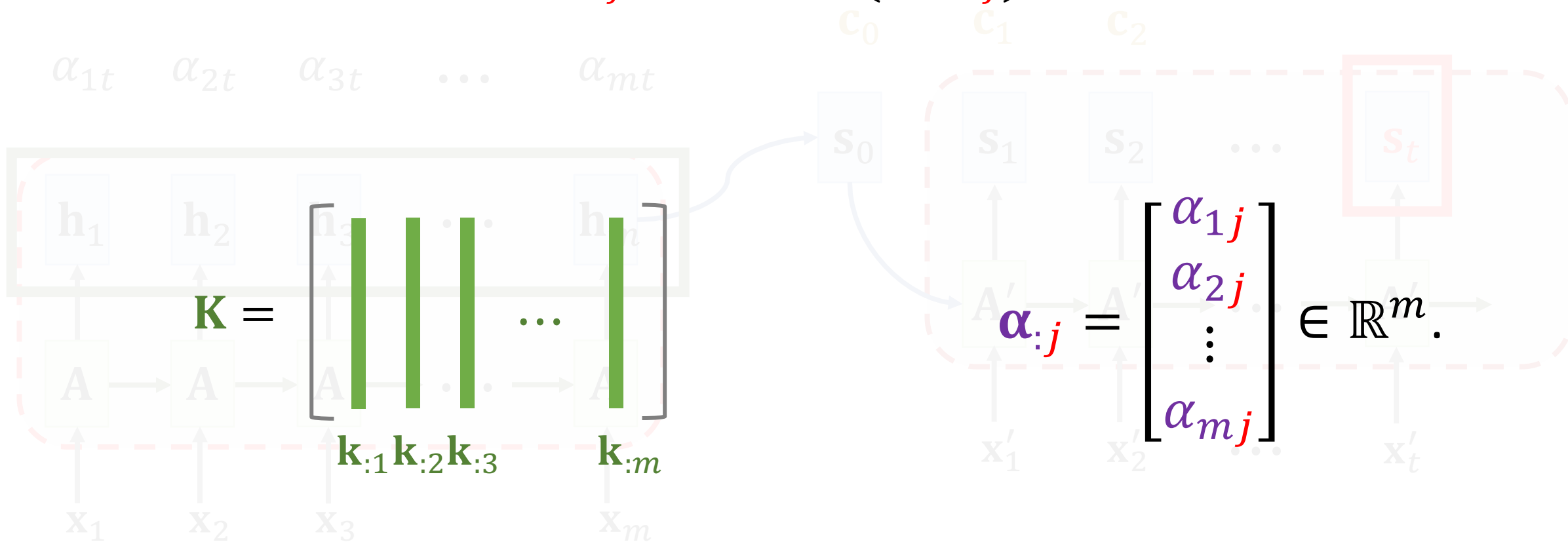
- Compute $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$ and $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$.



Attention for Seq2Seq Model

Weights: $\alpha_{ij} = \text{align}(\mathbf{h}_i, \mathbf{s}_j)$.

- Compute $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$ and $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$.
- Compute weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.

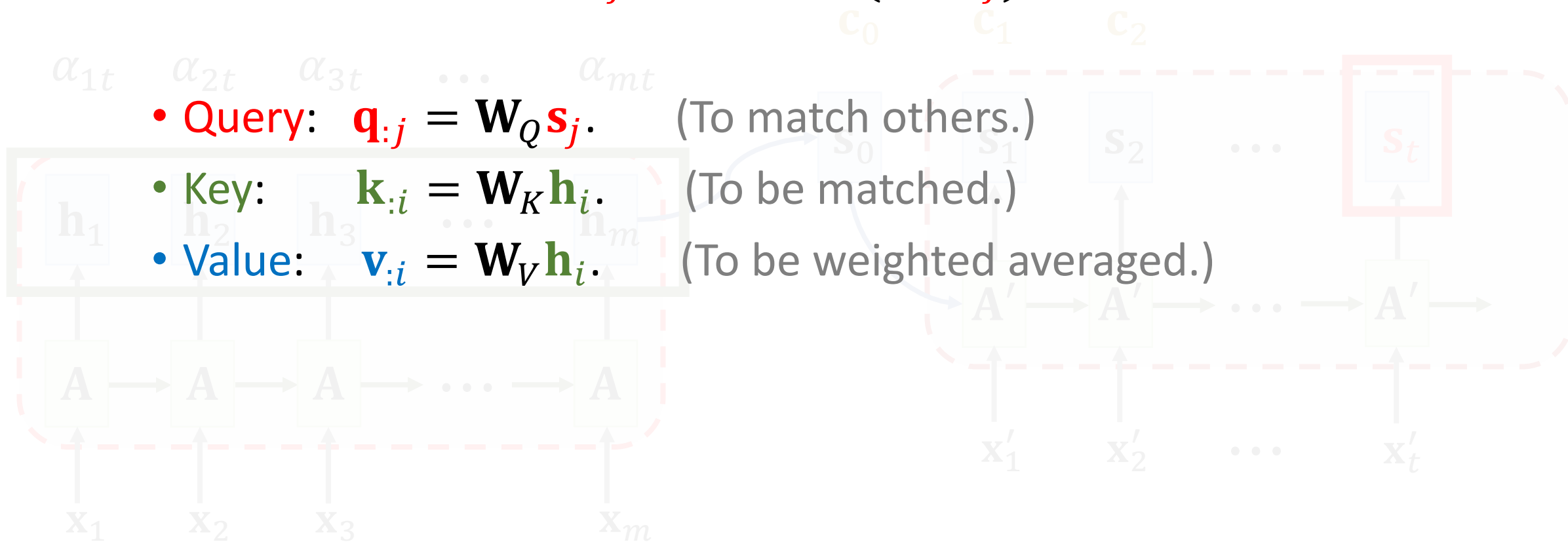


Attention for Seq2Seq Model

Weights: $\alpha_{ij} = \text{align}(\mathbf{h}_i, \mathbf{s}_j)$.

- Compute $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$ and $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$.
- Compute weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.

- **Query:** $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$. (To match others.)
- **Key:** $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$. (To be matched.)
- **Value:** $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$. (To be weighted averaged.)

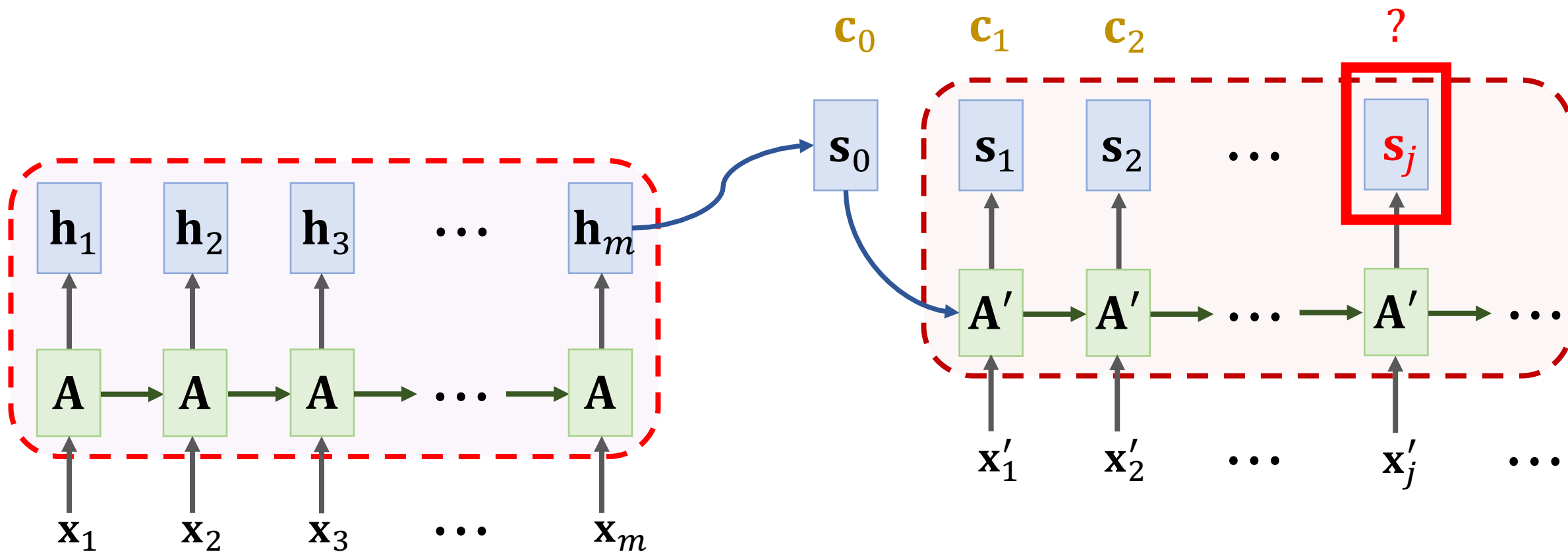


Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$,

Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$,

Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

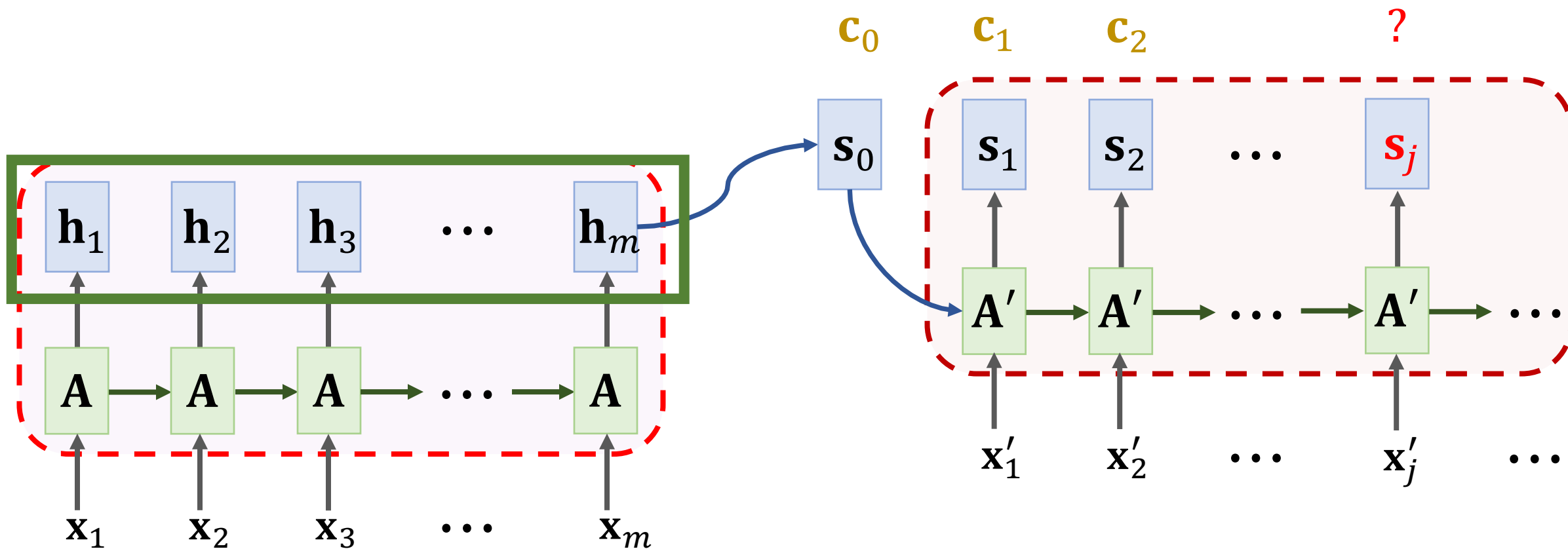


Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$,

Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$,

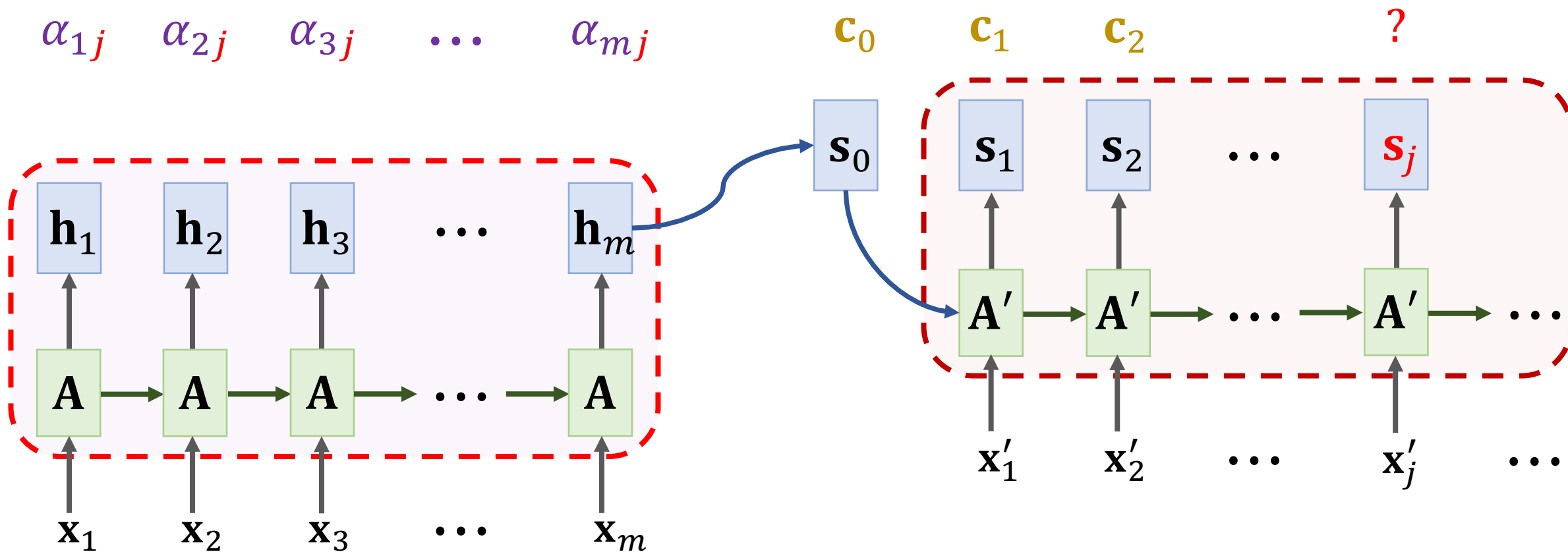
Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.



Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

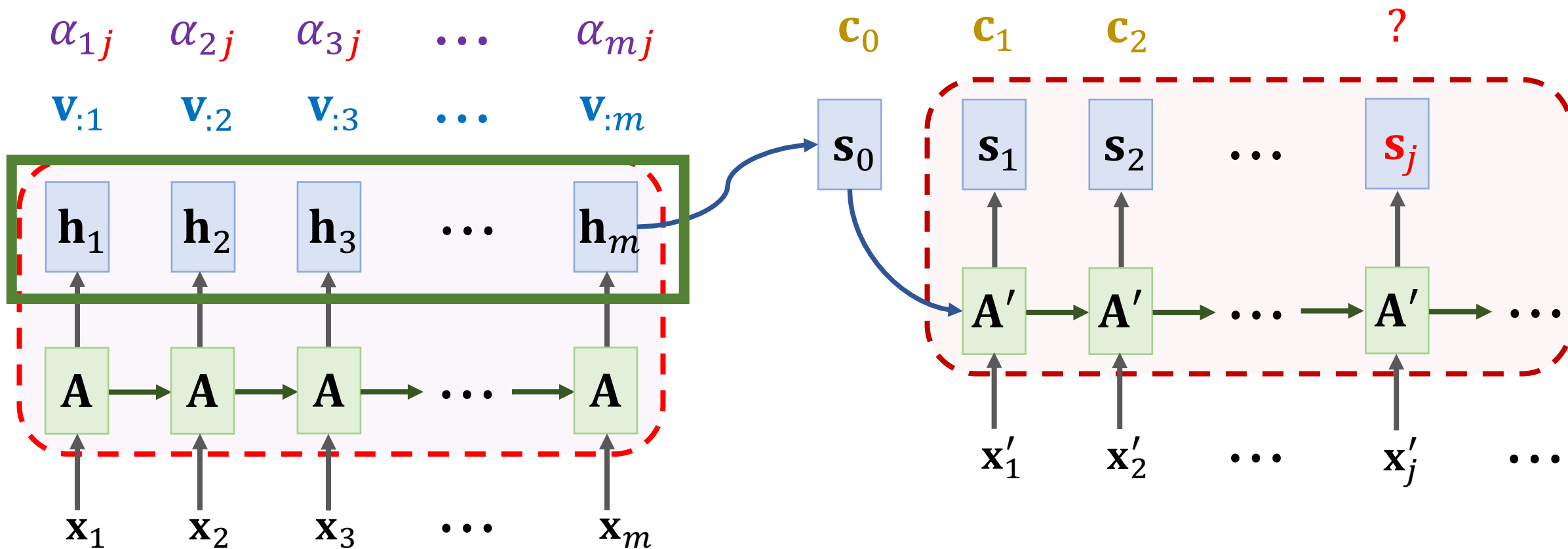
Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.



Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

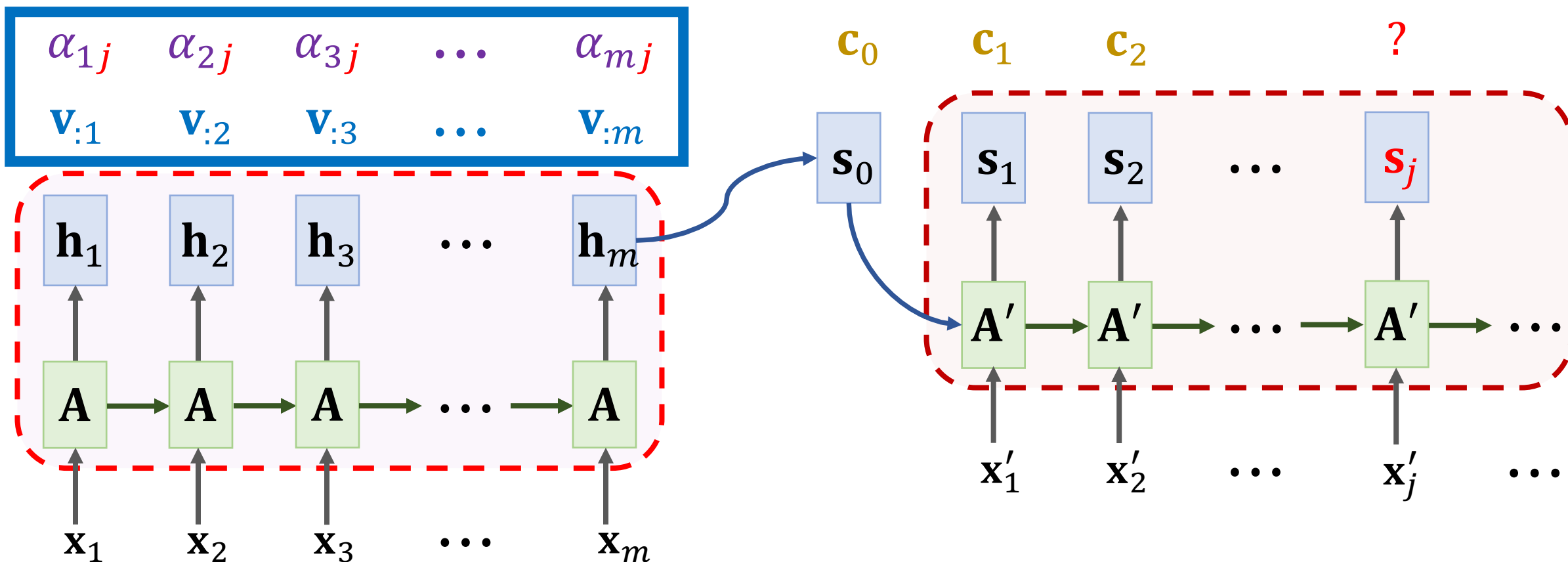
Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.



Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.

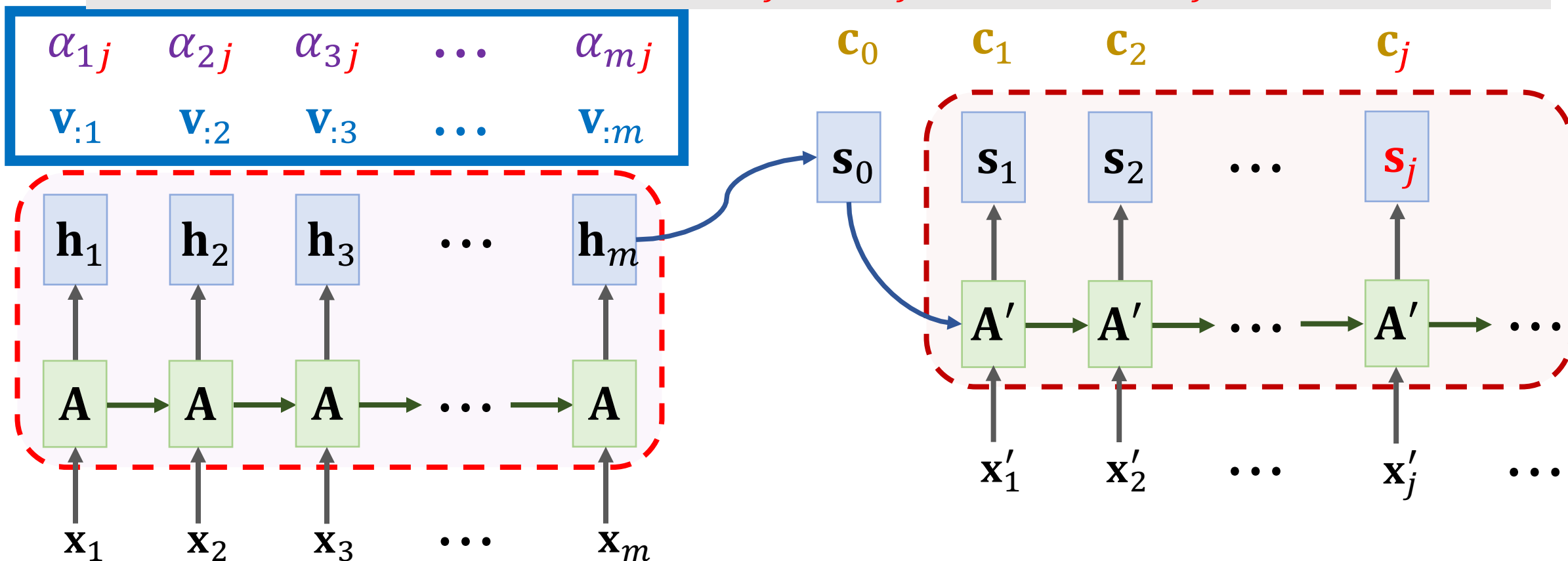


Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.

Context vector: $\mathbf{c}_j = \alpha_{1j} \mathbf{v}_{:1} + \cdots + \alpha_{mj} \mathbf{v}_{:m}$.



Attention for Seq2Seq Model

Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{s}_j$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{h}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{h}_i$.

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.

Context vector: $\mathbf{c}_j = \alpha_{1j} \mathbf{v}_{:1} + \cdots + \alpha_{mj} \mathbf{v}_{:m}$.

Question: How to remove RNN while keeping attention?

Attention without RNN

Attention Layer

- We study Seq2Seq model (encoder + decoder).
- Encoder's inputs are vectors $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m$.
- Decoder's inputs are vectors $\mathbf{x}'_1, \mathbf{x}'_2, \dots, \mathbf{x}'_t$.

Encoder's inputs:

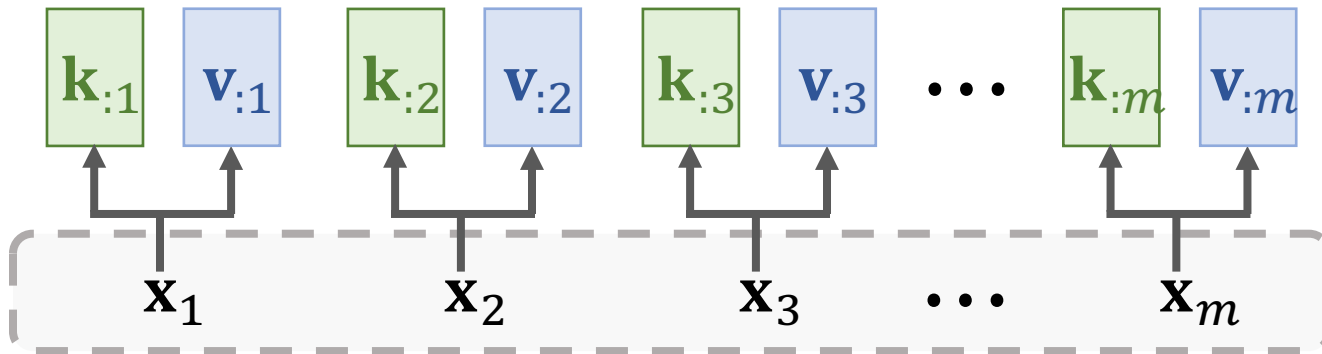


Decoder's inputs:



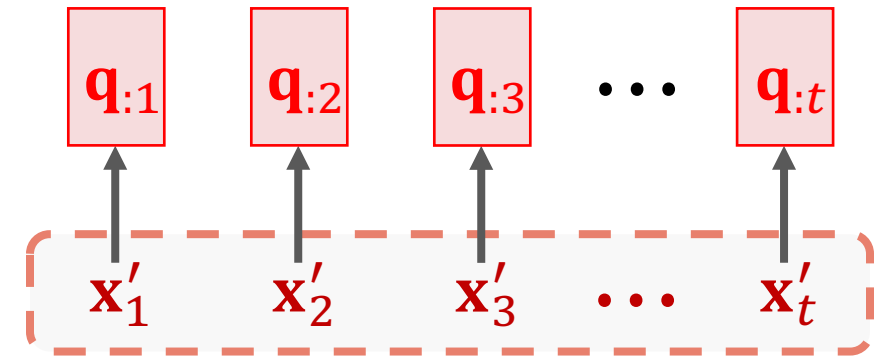
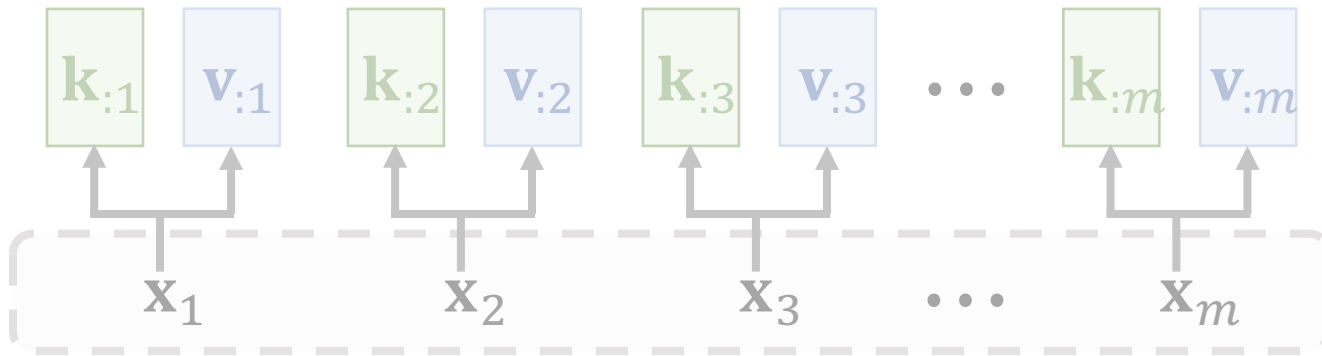
Attention Layer

- **Keys** and **values** are based on encoder's inputs $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m$.
- **Key:** $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{x}_i$.
- **Value:** $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{x}_i$.



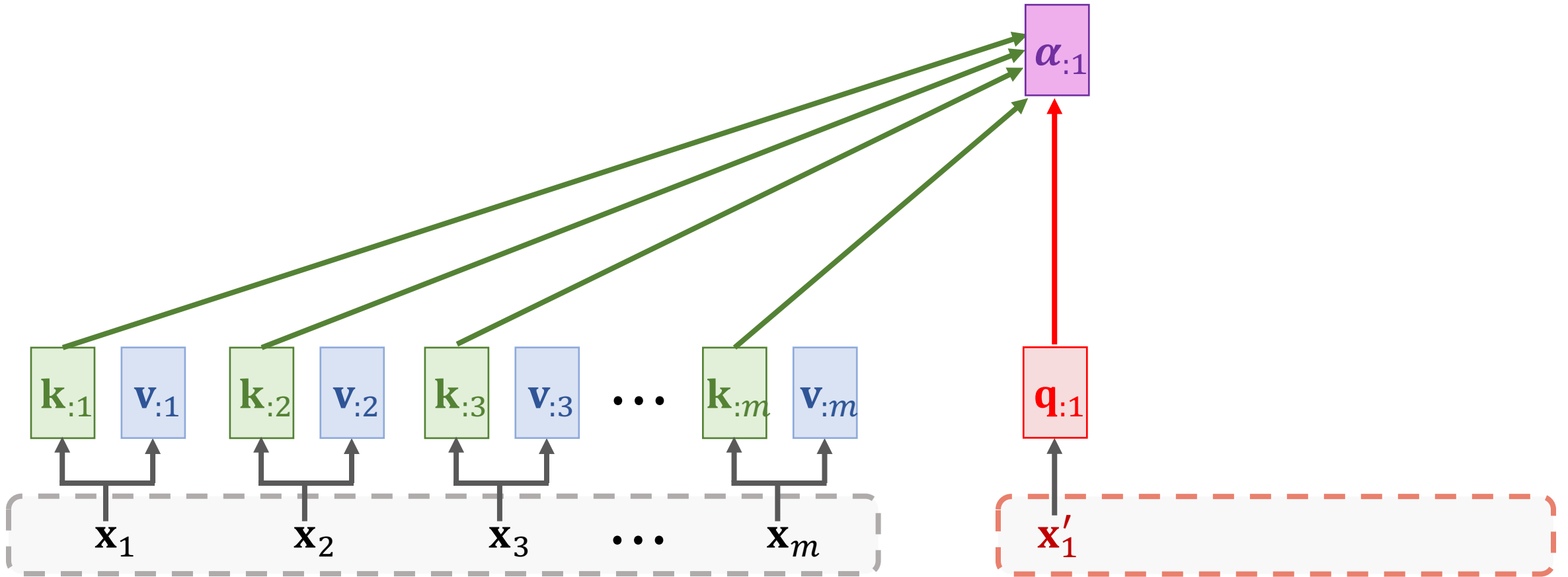
Attention Layer

- **Keys** and **values** are based on encoder's inputs $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m$.
- **Key:** $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{x}_i$.
- **Value:** $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{x}_i$.
- **Queries** are based on decoder's inputs $\mathbf{x}'_1, \mathbf{x}'_2, \dots, \mathbf{x}'_t$.
- **Query:** $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{x}'_j$.



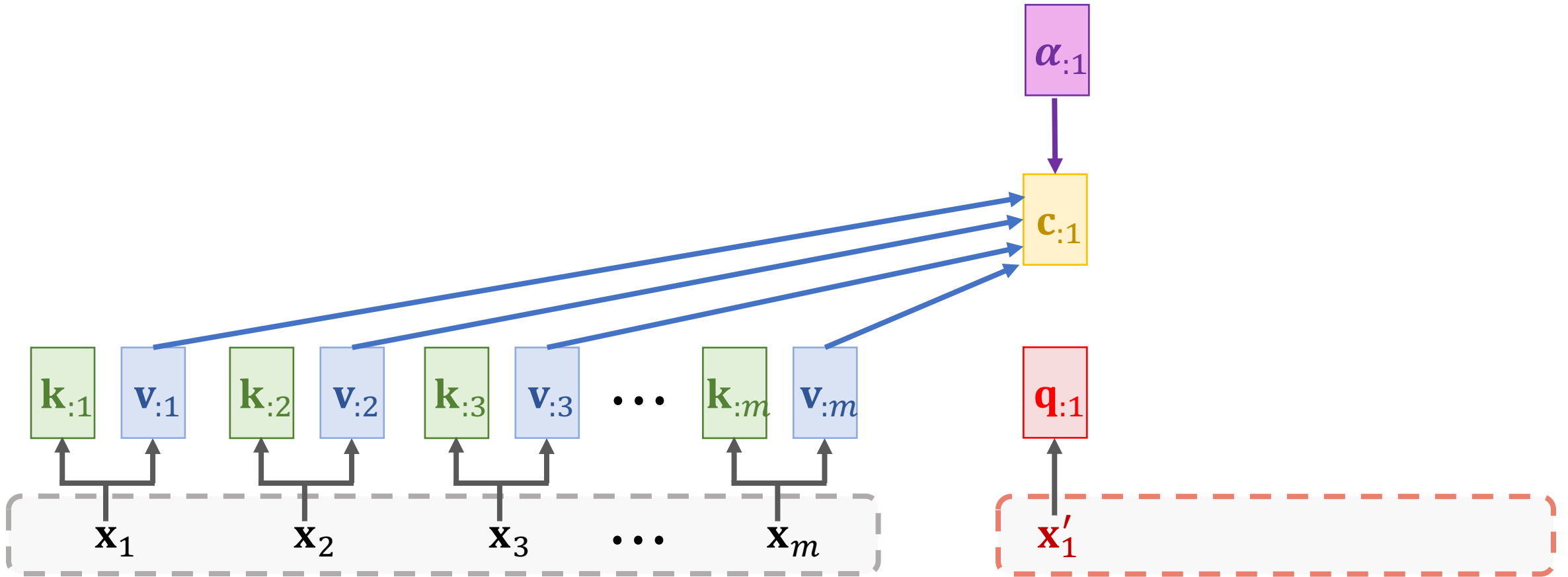
Attention Layer

- Compute weights: $\alpha_{:1} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:1}) \in \mathbb{R}^m$.



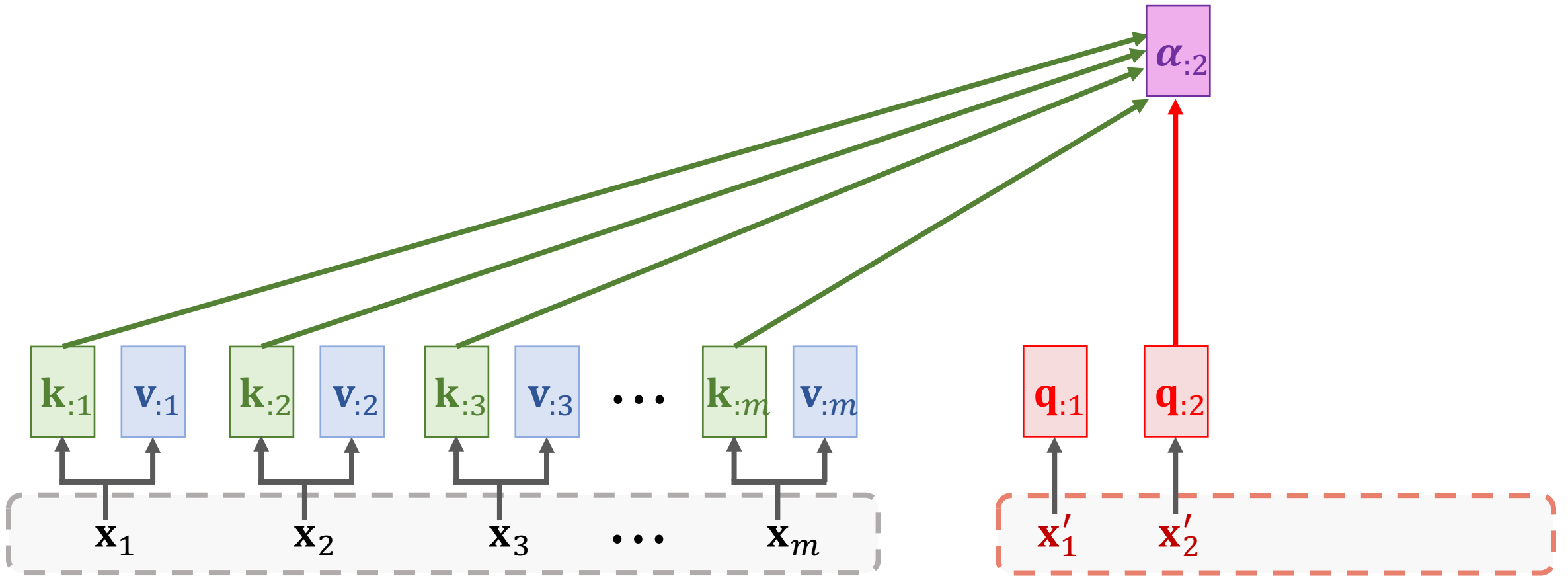
Attention Layer

- Compute context vector: $\mathbf{c}_{:1} = \alpha_{11}\mathbf{v}_{:1} + \dots + \alpha_{m1}\mathbf{v}_{:m} = \mathbf{V}\boldsymbol{\alpha}_{:1}$.



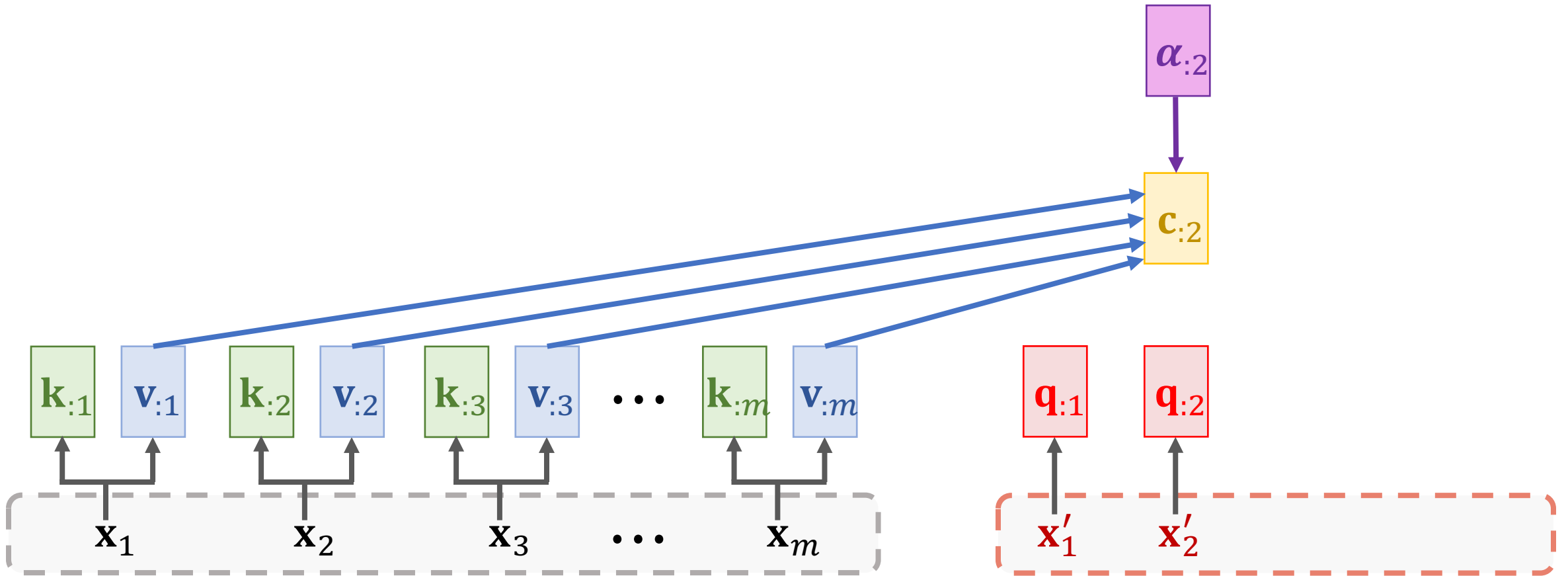
Attention Layer

- Compute weights: $\alpha_{:2} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:2}) \in \mathbb{R}^m$.



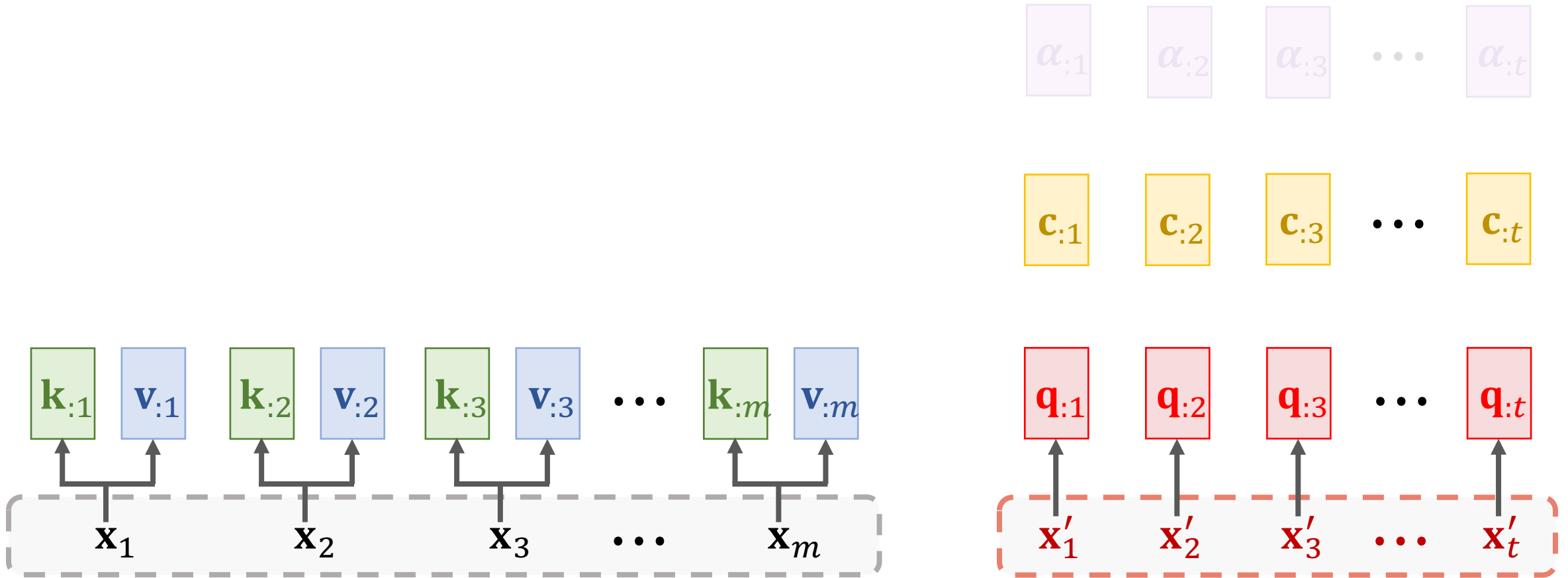
Attention Layer

- Compute context vector: $\mathbf{c}_{:2} = \alpha_{12}\mathbf{v}_{:1} + \cdots + \alpha_{m2}\mathbf{v}_{:m} = \mathbf{V}\boldsymbol{\alpha}_{:2}$.



Attention Layer

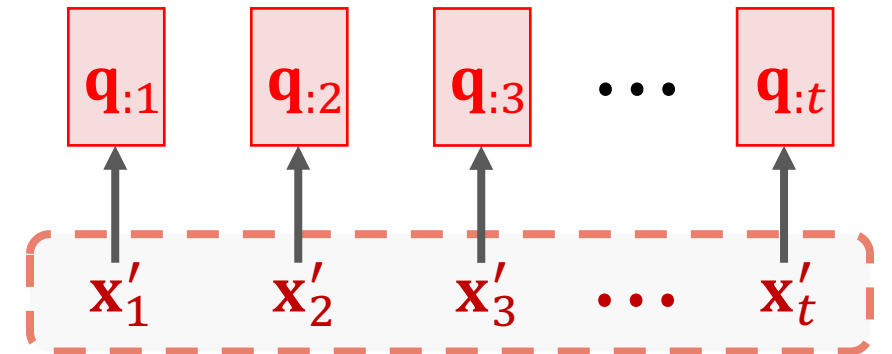
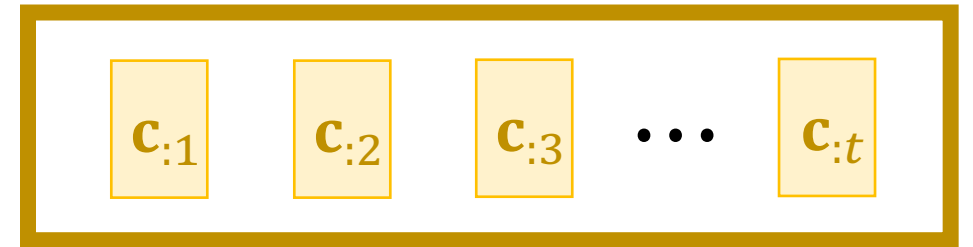
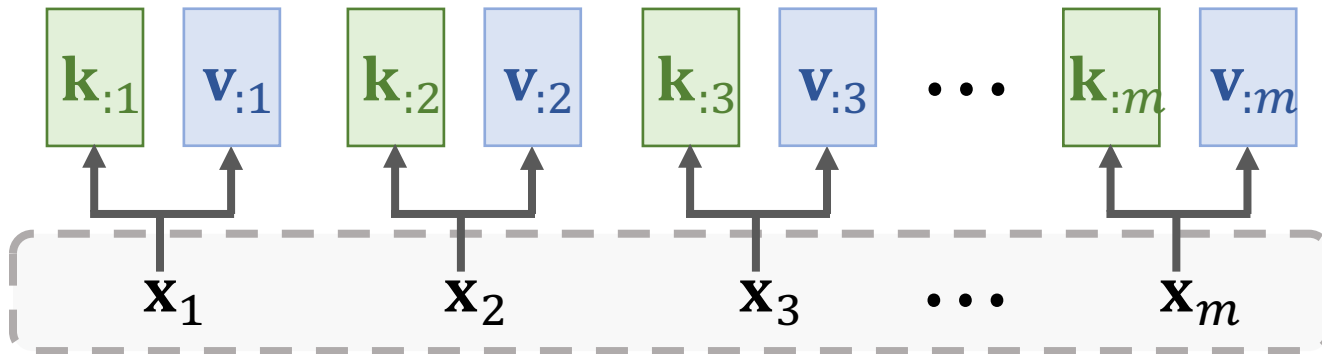
- Compute context vector: $\mathbf{c}_{:j} = \alpha_{1j}\mathbf{v}_{:1} + \cdots + \alpha_{mj}\mathbf{v}_{:m} = \mathbf{V}\boldsymbol{\alpha}_{:j}$.



Attention Layer

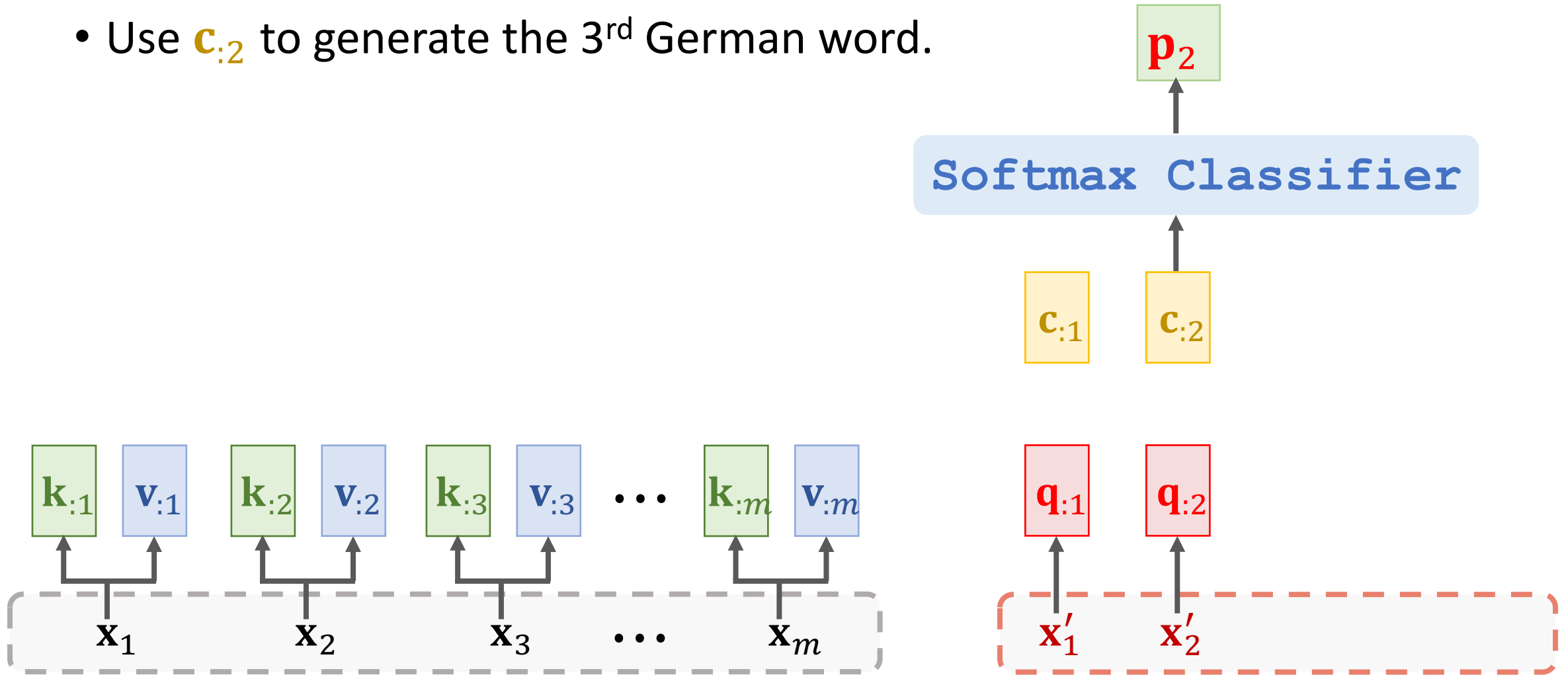
- Output of attention layer: $\mathbf{C} = [\mathbf{c}_{:1}, \mathbf{c}_{:2}, \mathbf{c}_{:3}, \dots, \mathbf{c}_{:t}]$.
- Here, $\mathbf{c}_{:j} = \mathbf{V} \cdot \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j})$.
- Thus, $\mathbf{c}_{:j}$ is a function of \mathbf{x}'_j and $[\mathbf{x}_1, \dots, \mathbf{x}_m]$.

Output of attention layer:



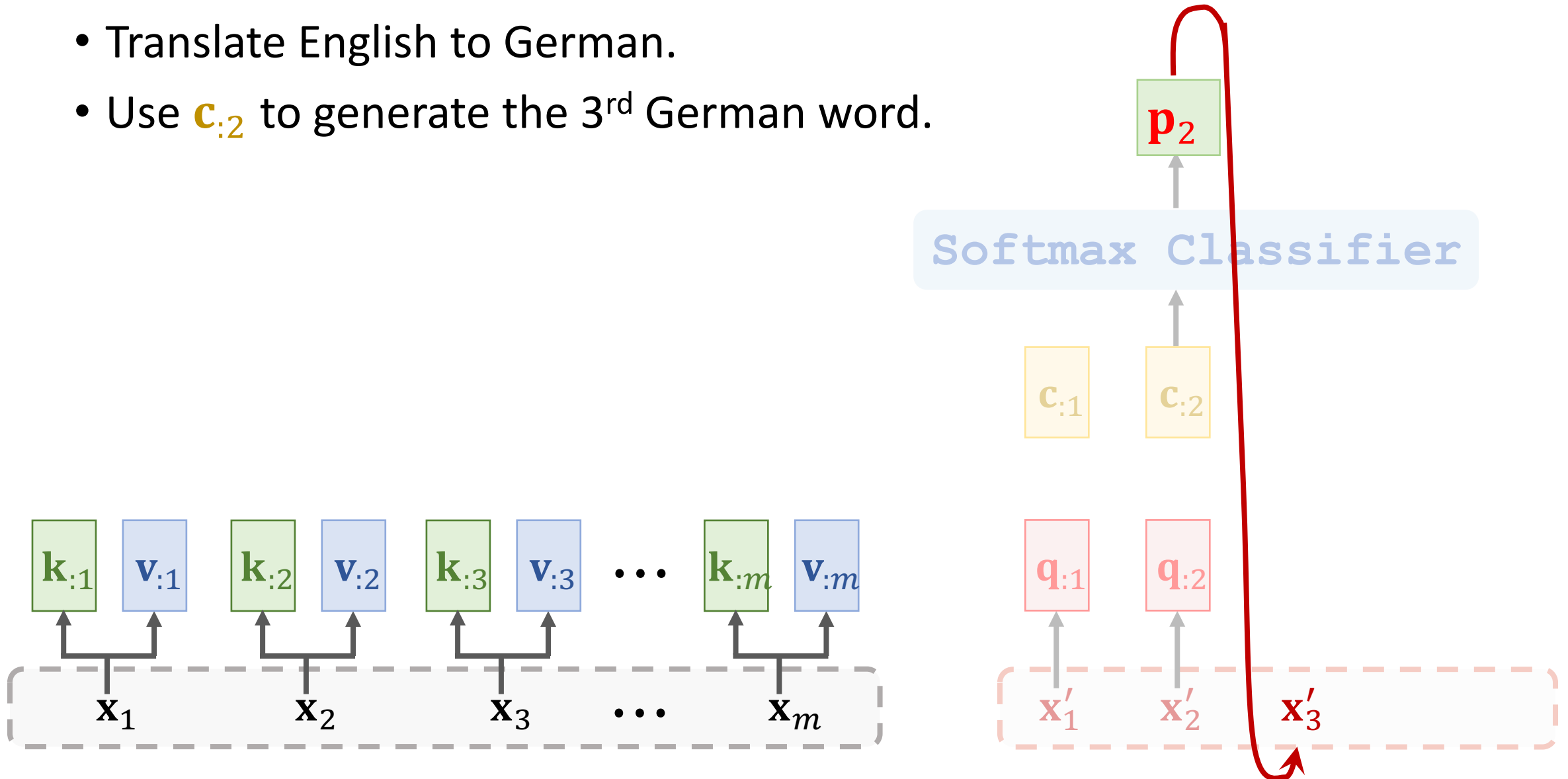
Attention Layer for Machine Translation

- Translate English to German.
- Use $\mathbf{c}_{:2}$ to generate the 3rd German word.



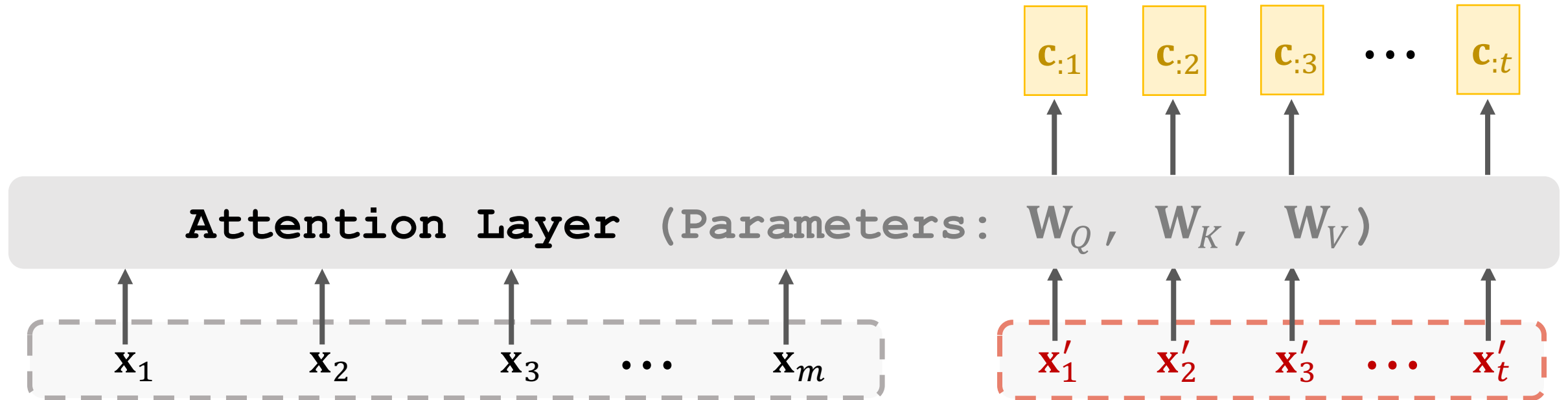
Attention Layer for Machine Translation

- Translate English to German.
- Use $\mathbf{c}_{:2}$ to generate the 3rd German word.



Attention Layer

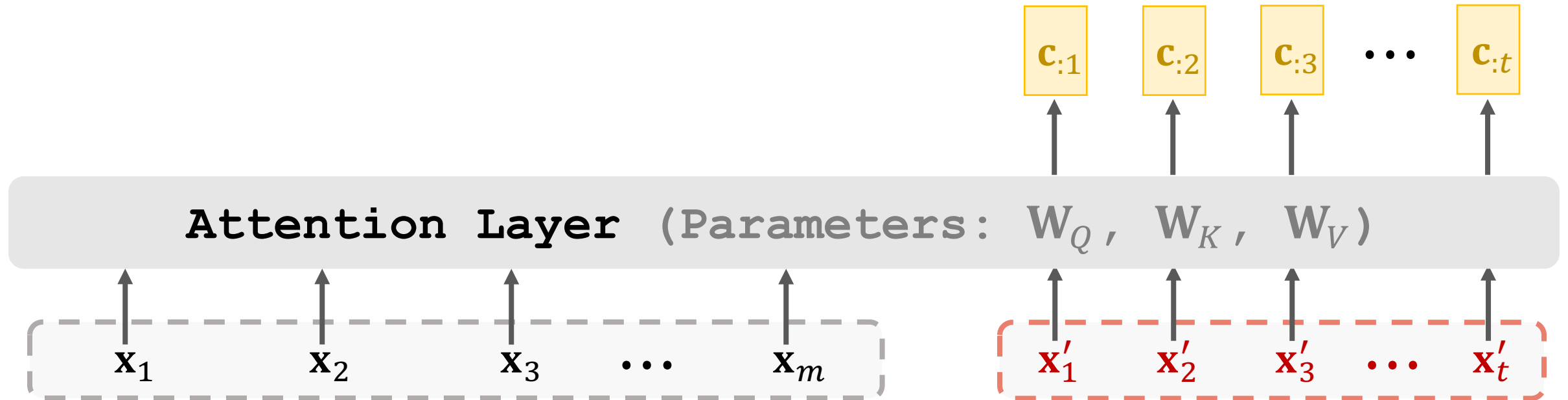
- Attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X}')$.
 - Encoder's inputs: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m]$.
 - Decoder's inputs: $\mathbf{X}' = [\mathbf{x}'_1, \mathbf{x}'_2, \dots, \mathbf{x}'_t]$.
 - Parameters: \mathbf{W}_Q , \mathbf{W}_K , \mathbf{W}_V .



Self-Attention without RNN

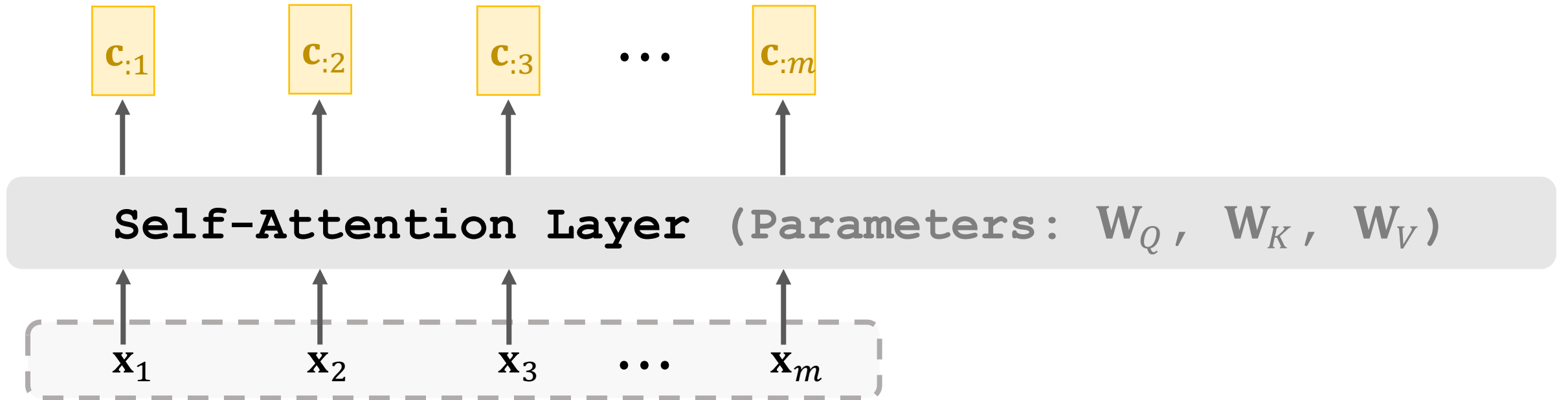
Attention Layer

- Attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X}')$.
 - Encoder's inputs: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m]$.
 - Decoder's inputs: $\mathbf{X}' = [\mathbf{x}'_1, \mathbf{x}'_2, \dots, \mathbf{x}'_m]$.
 - Parameters: \mathbf{W}_Q , \mathbf{W}_K , \mathbf{W}_V .



Self-Attention Layer

- Self-attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X})$.
 - Inputs: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m]$.
 - Parameters: $\mathbf{W}_Q, \mathbf{W}_K, \mathbf{W}_V$.



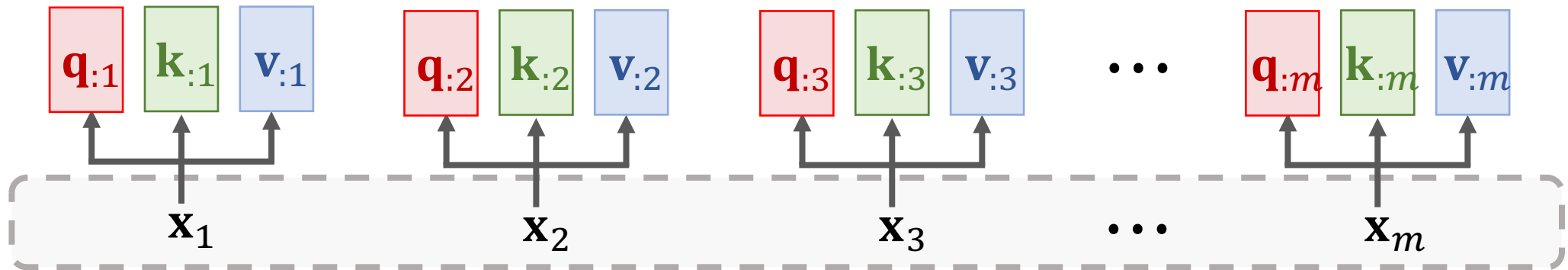
Self-Attention Layer

Inputs:



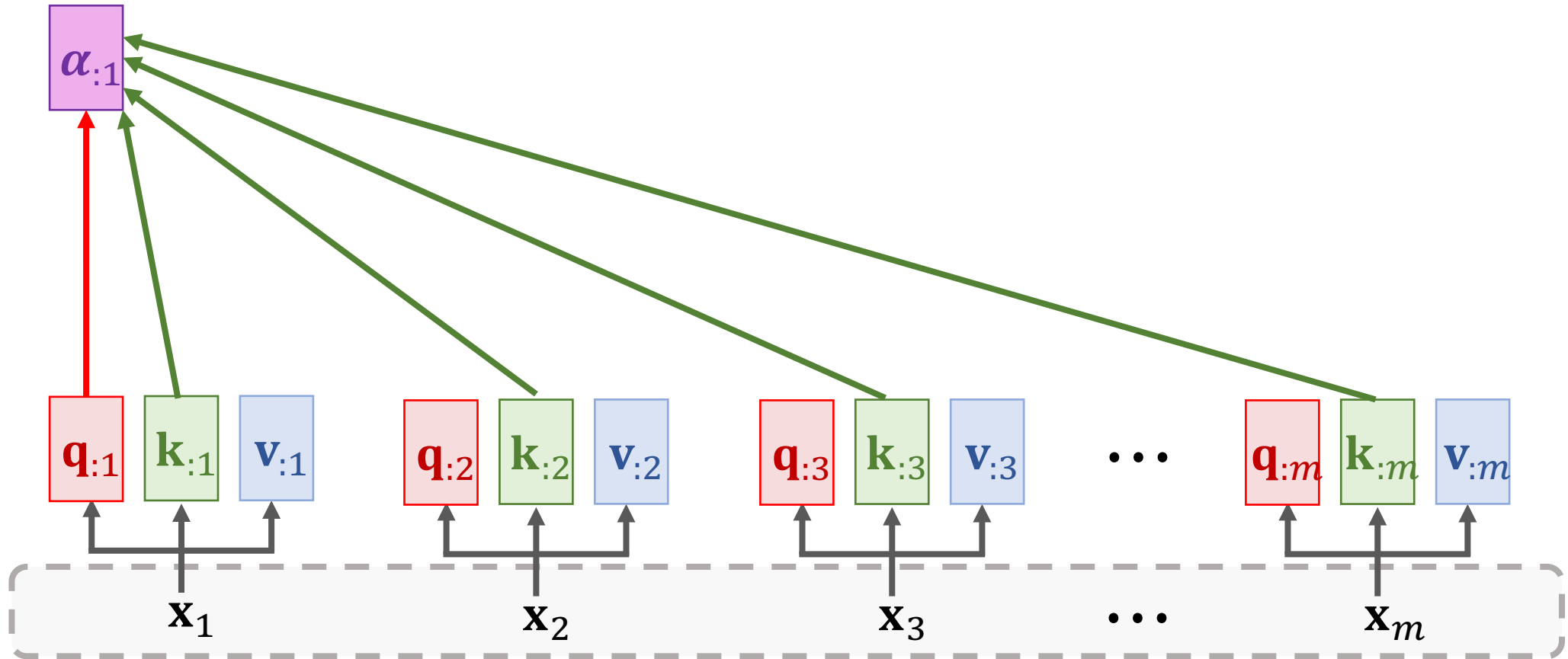
Self-Attention Layer

Query: $\mathbf{q}_{:i} = \mathbf{W}_Q \mathbf{x}_i$, Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{x}_i$, Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{x}_i$.



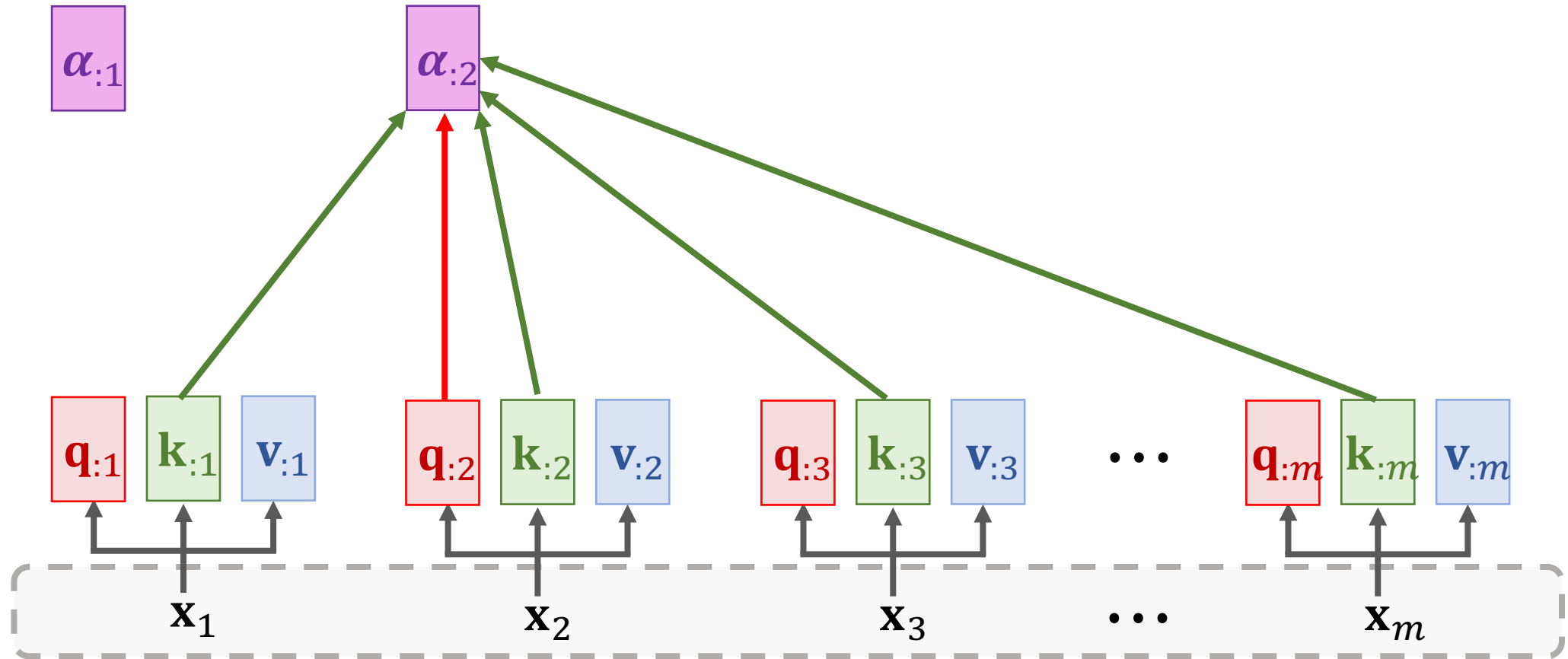
Self-Attention Layer

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.



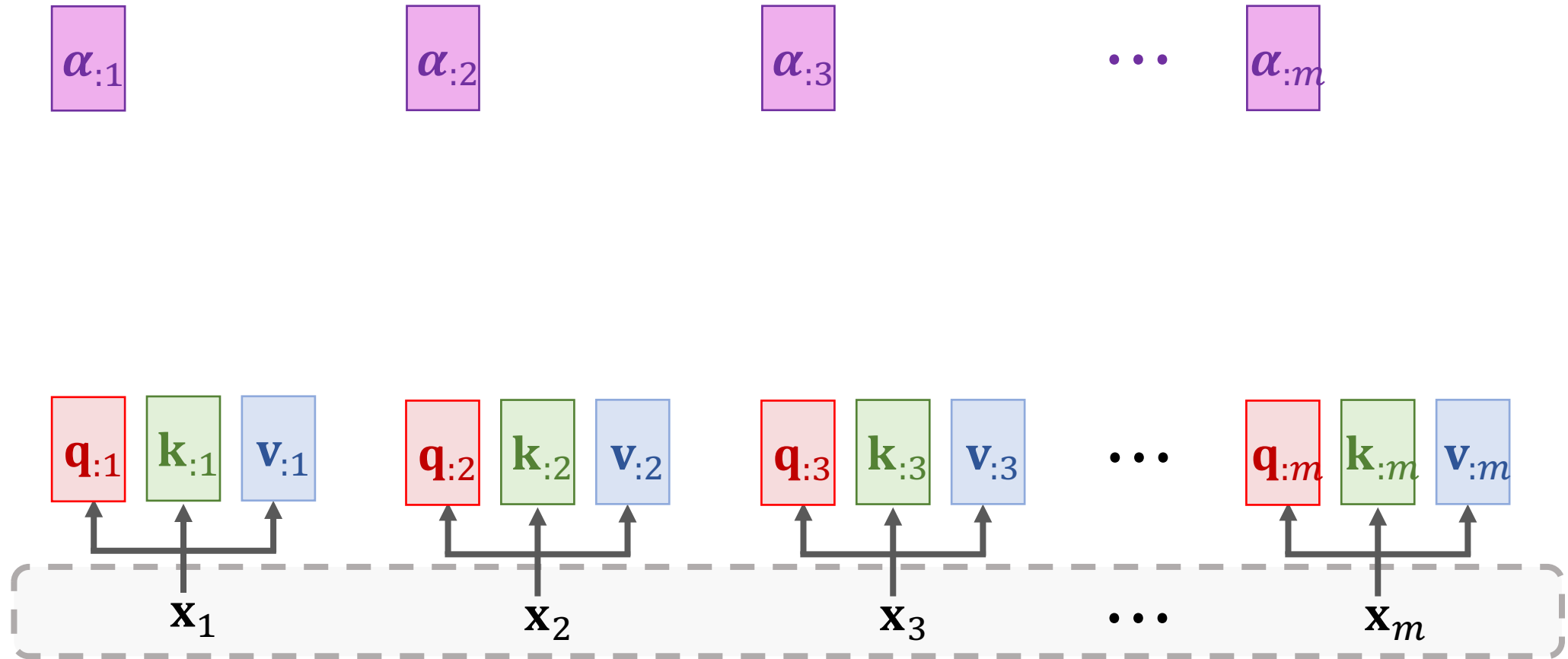
Self-Attention Layer

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.



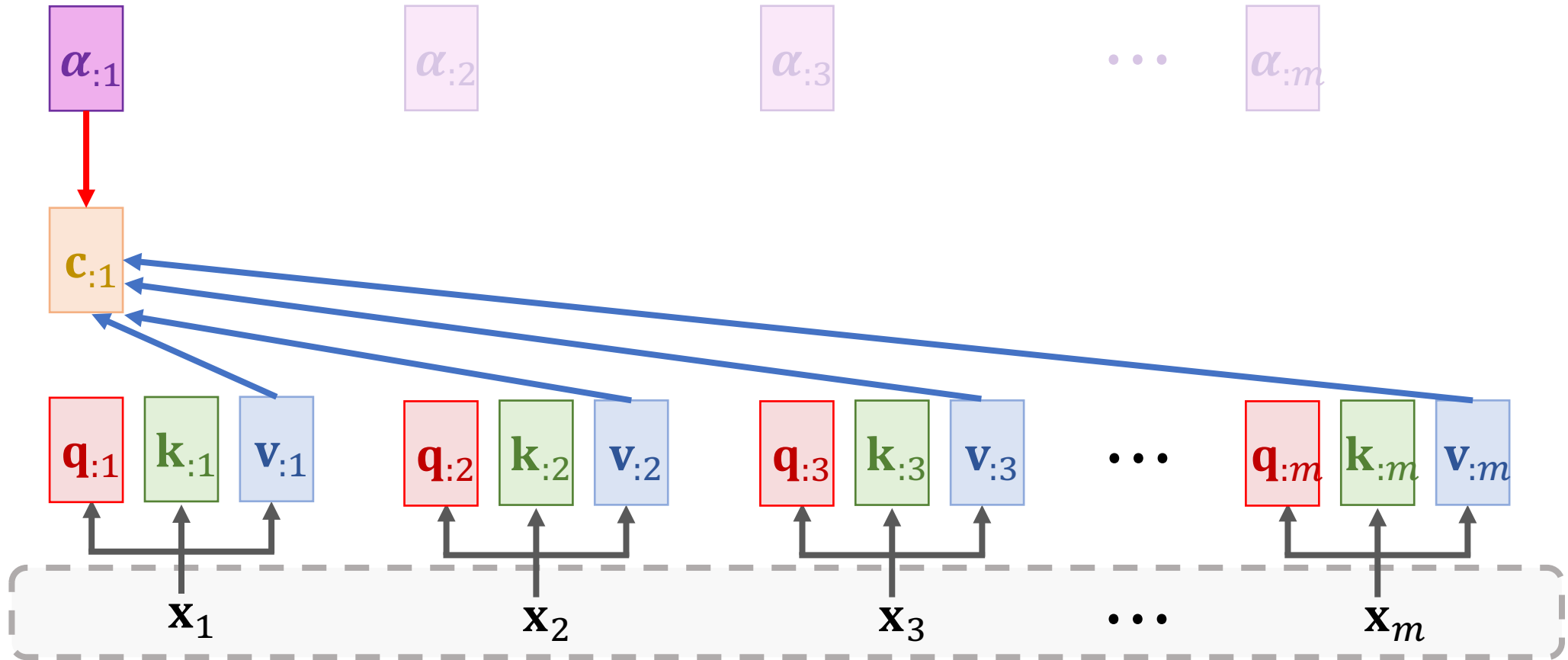
Self-Attention Layer

Weights: $\alpha_{:j} = \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j}) \in \mathbb{R}^m$.



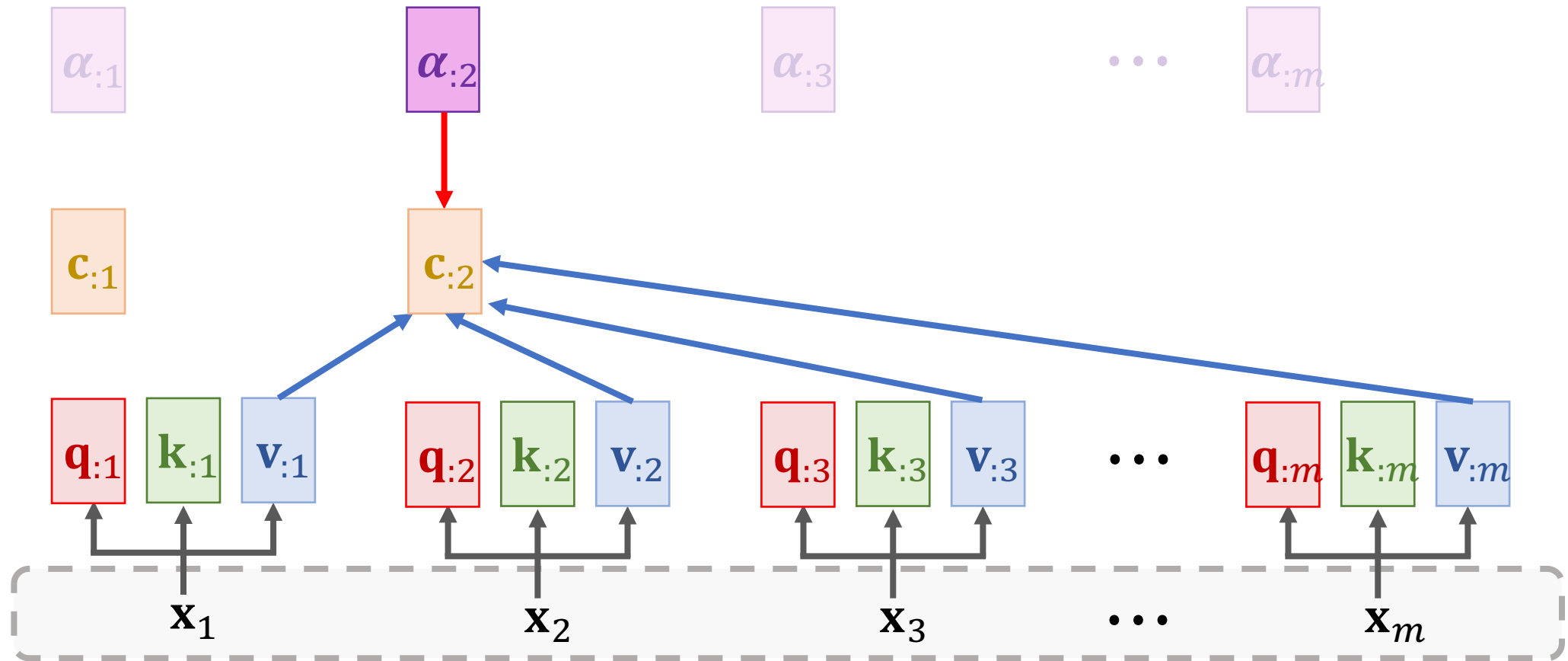
Self-Attention Layer

Context vector: $\mathbf{c}_{:1} = \alpha_{11}\mathbf{v}_{:1} + \dots + \alpha_{m1}\mathbf{v}_{:m} = \mathbf{V}\boldsymbol{\alpha}_{:1}.$



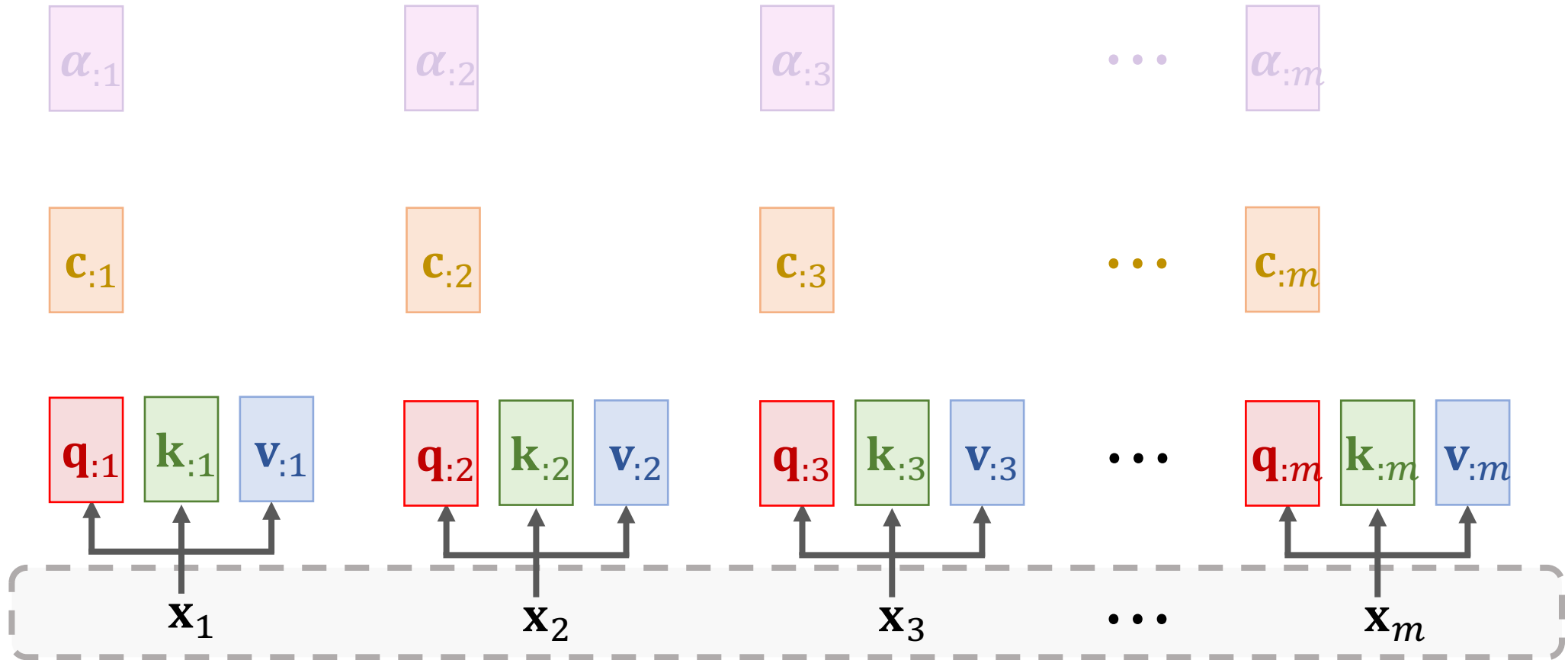
Self-Attention Layer

Context vector: $\mathbf{c}_{:2} = \alpha_{12}\mathbf{v}_{:1} + \dots + \alpha_{m2}\mathbf{v}_{:m} = \mathbf{V}\alpha_{:2}.$



Self-Attention Layer

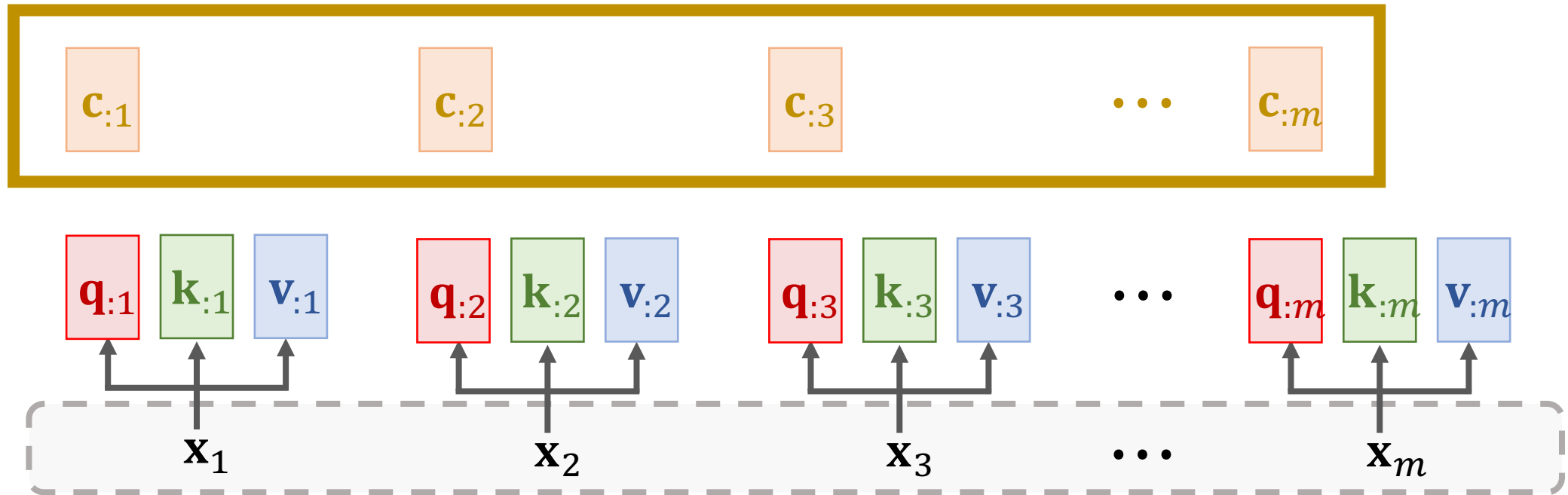
Context vector: $\mathbf{c}_{:j} = \alpha_{1j}\mathbf{v}_{:1} + \cdots + \alpha_{mj}\mathbf{v}_{:m} = \mathbf{V}\boldsymbol{\alpha}_{:j}.$



Self-Attention Layer

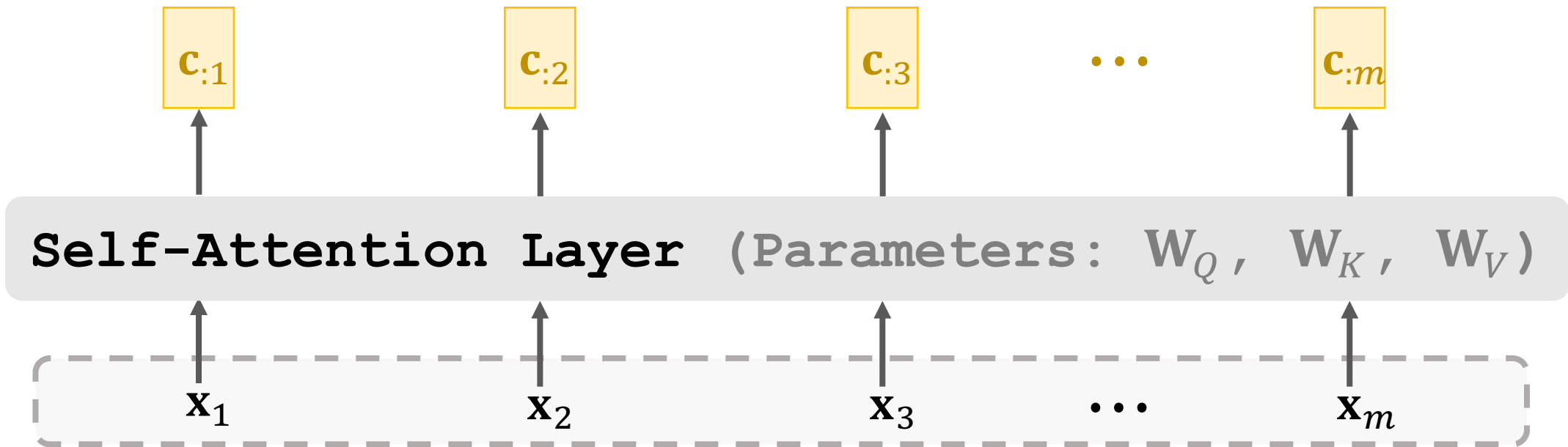
- Here, $\mathbf{c}_{:j} = \mathbf{V} \cdot \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j})$.
- Thus, $\mathbf{c}_{:j}$ is a function of all the m vectors $\mathbf{x}_1, \dots, \mathbf{x}_m$.

Output of self-attention layer:



Self-Attention Layer

- Self-attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X})$.
 - Inputs: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_m]$.
 - Parameters: \mathbf{W}_Q , \mathbf{W}_K , \mathbf{W}_V .



Summary

Summary

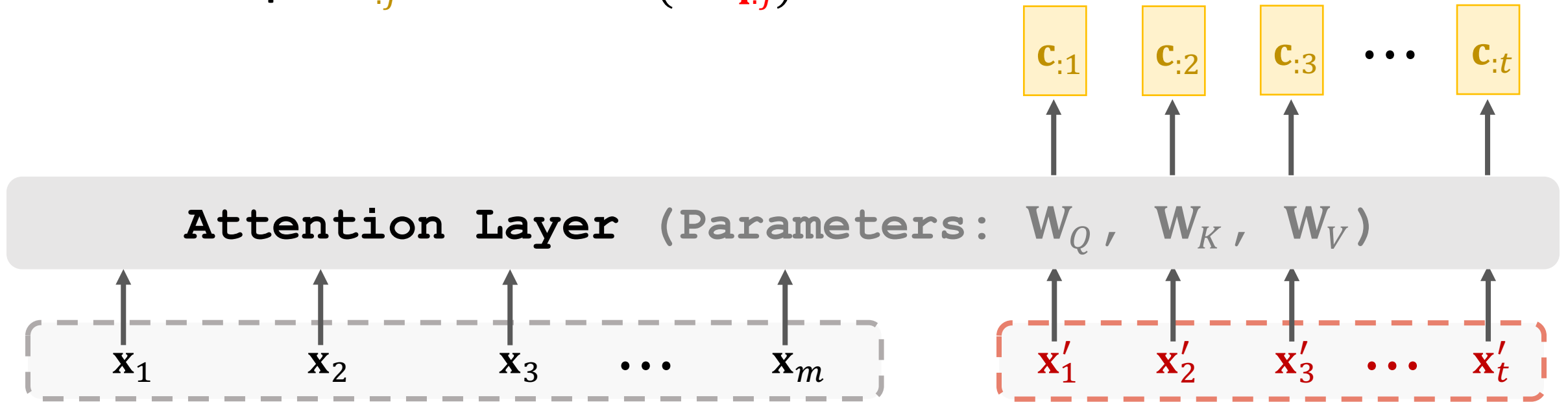
- Attention was originally developed for Seq2Seq RNN models [1].
- Self-attention: attention for all the RNN models (not necessarily Seq2Seq models [2]).
- Attention can be used without RNN [3].
- We learned how to build attention layer and self-attention layer.

Reference:

1. Bahdanau, Cho, & Bengio. [Neural machine translation by jointly learning to align and translate](#). In *ICLR*, 2015.
2. Cheng, Dong, & Lapata. [Long Short-Term Memory-Networks for Machine Reading](#). In *EMNLP*, 2016.
3. Vaswani et al. [Attention Is All You Need](#). In *NIPS*, 2017.

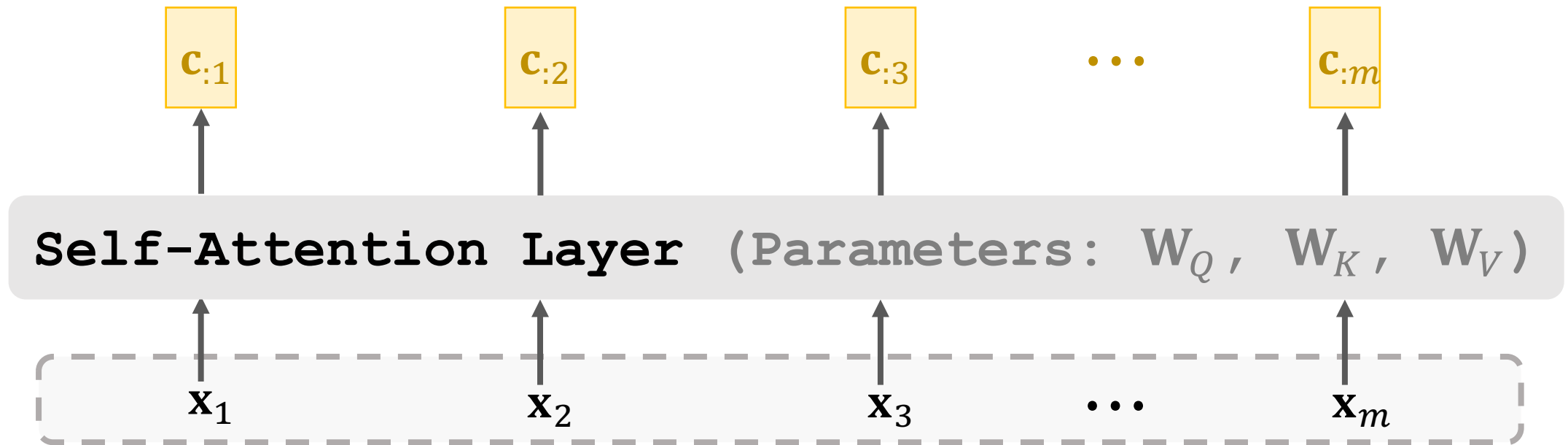
Attention Layer

- Attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X}')$.
 - Query: $\mathbf{q}_{:j} = \mathbf{W}_Q \mathbf{x}'_j$,
 - Key: $\mathbf{k}_{:i} = \mathbf{W}_K \mathbf{x}_i$,
 - Value: $\mathbf{v}_{:i} = \mathbf{W}_V \mathbf{x}_i$.
 - Output: $\mathbf{c}_{:j} = \mathbf{V} \cdot \text{Softmax}(\mathbf{K}^T \mathbf{q}_{:j})$.



Self-Attention Layer

- Attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X}')$.
- Self-Attention layer: $\mathbf{C} = \text{Attn}(\mathbf{X}, \mathbf{X})$.



Thank you!