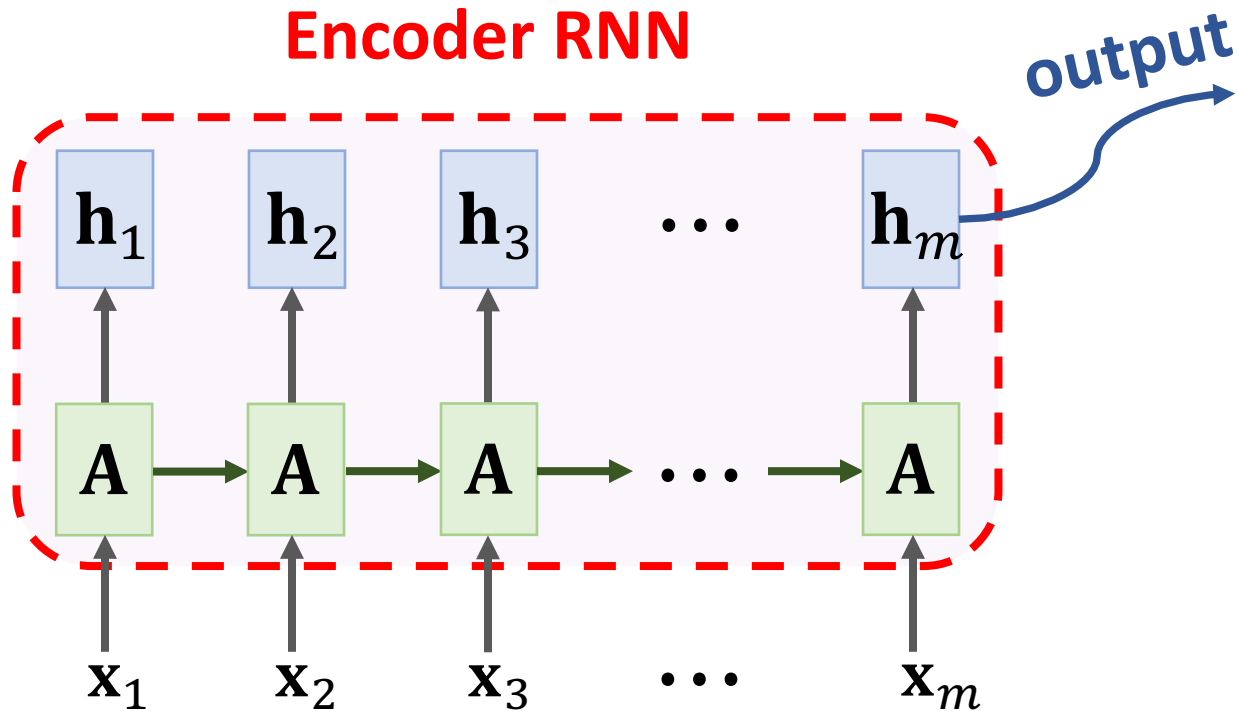


Attention

Shusen Wang

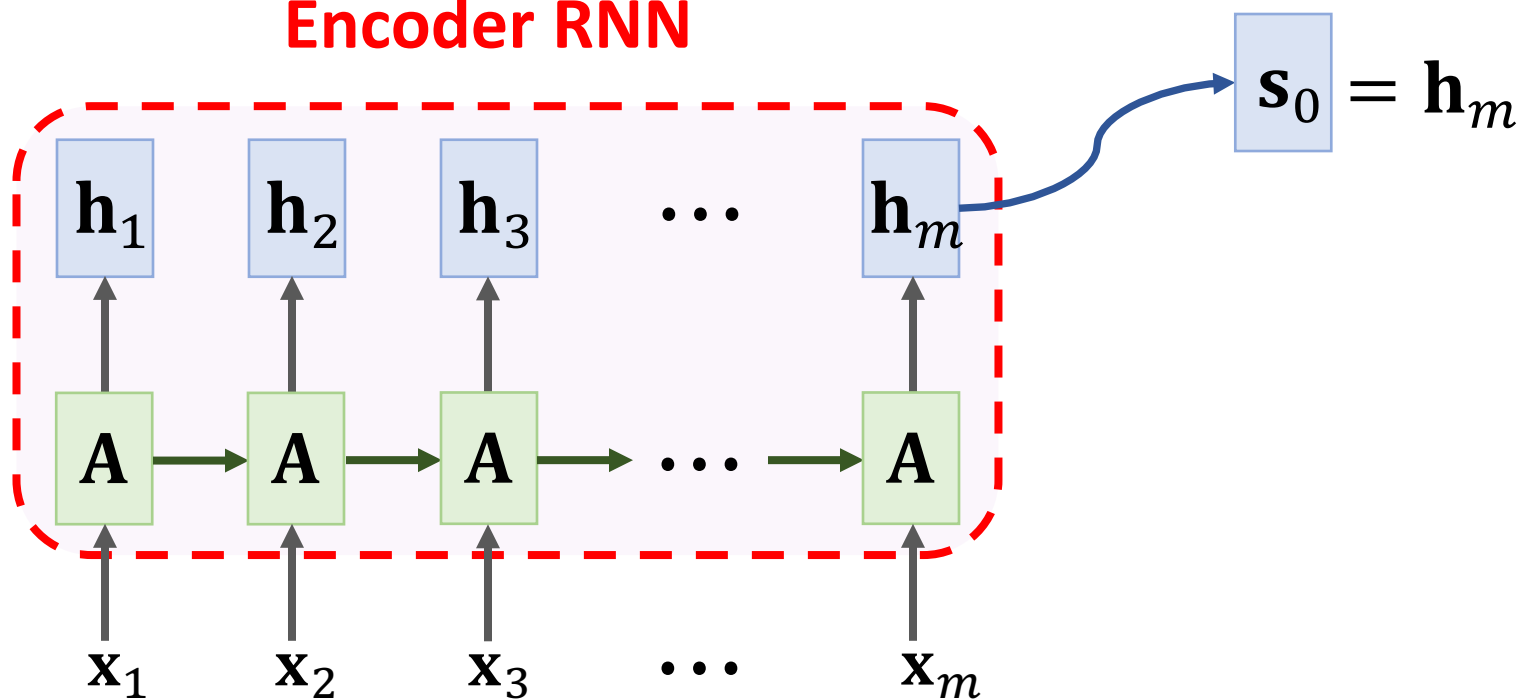
Seq2Seq Model

Encoder RNN



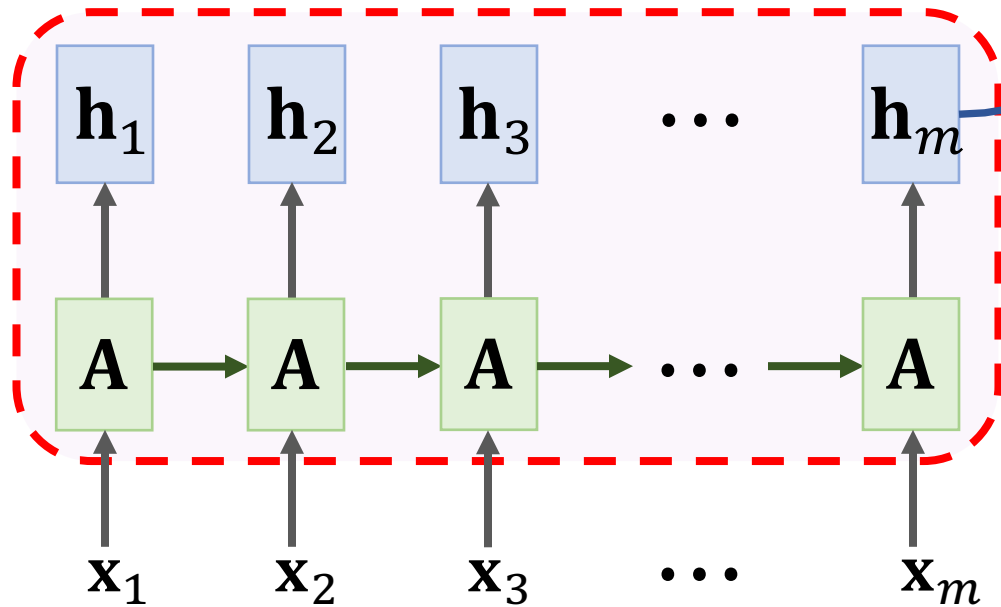
Seq2Seq Model

Encoder RNN

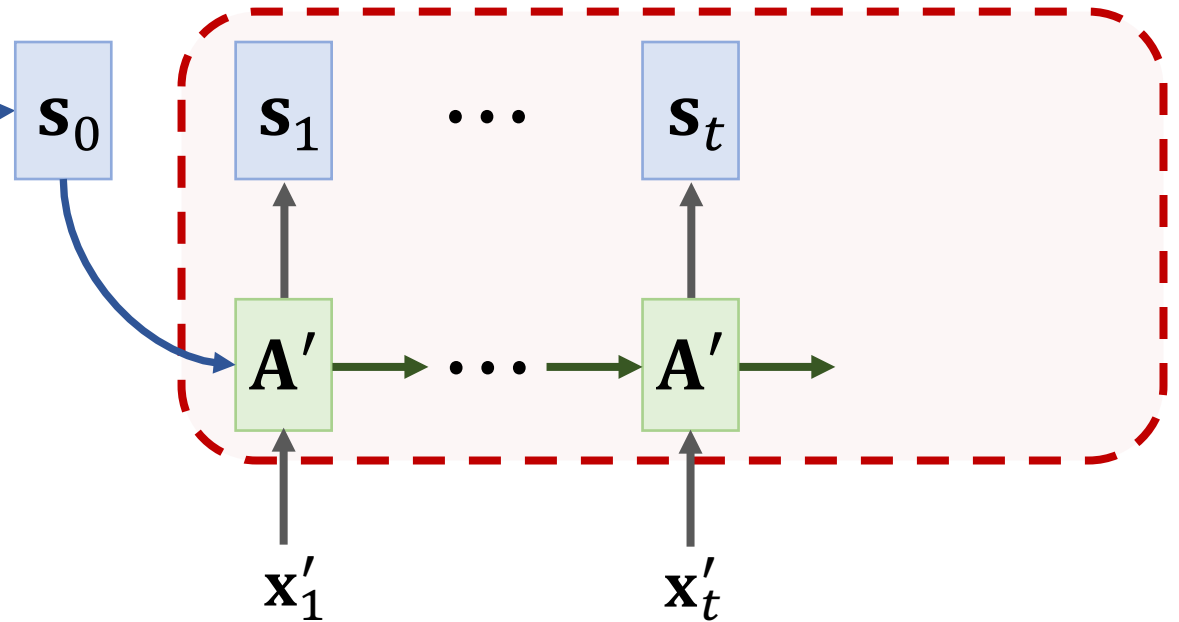


Seq2Seq Model

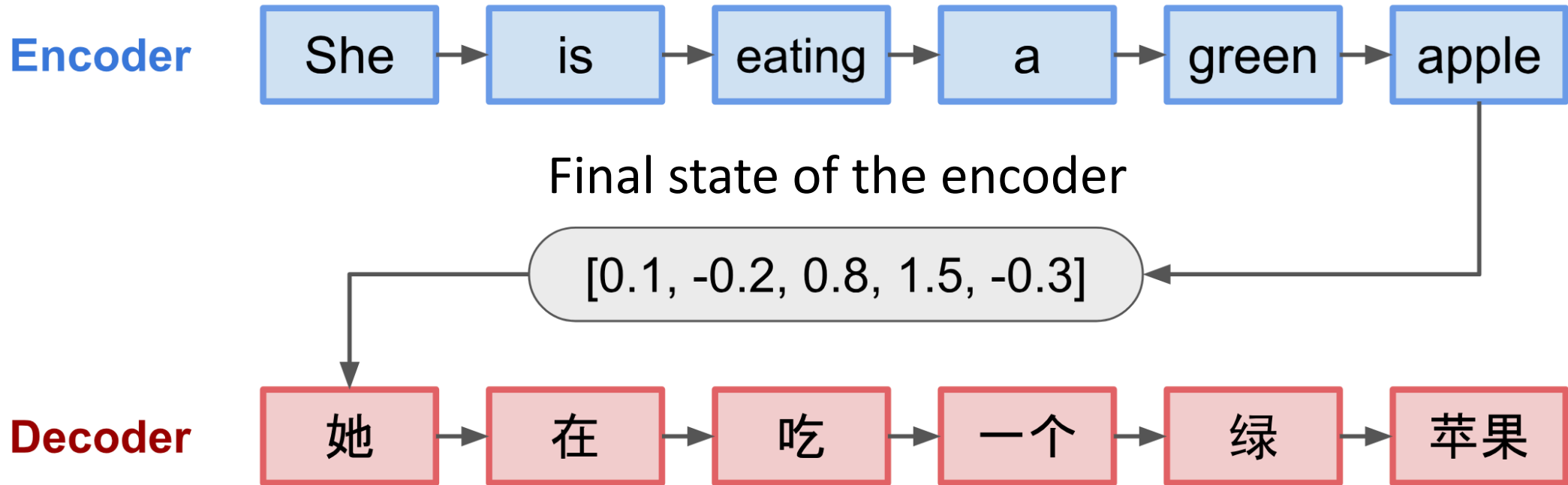
Encoder RNN



Decoder RNN



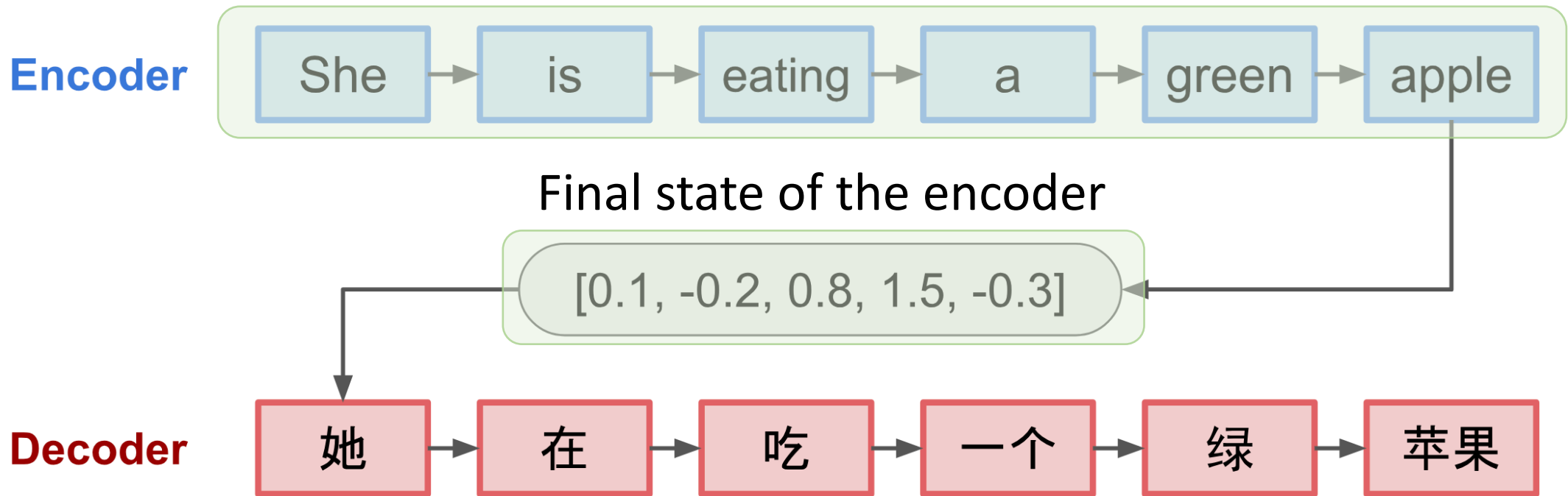
Seq2Seq Model



The figure is from blog.lilianweng.github.io

Seq2Seq Model

Shortcoming: The final state is incapable of remembering a **long** sequence.



The figure is from blog.lilianweng.github.io

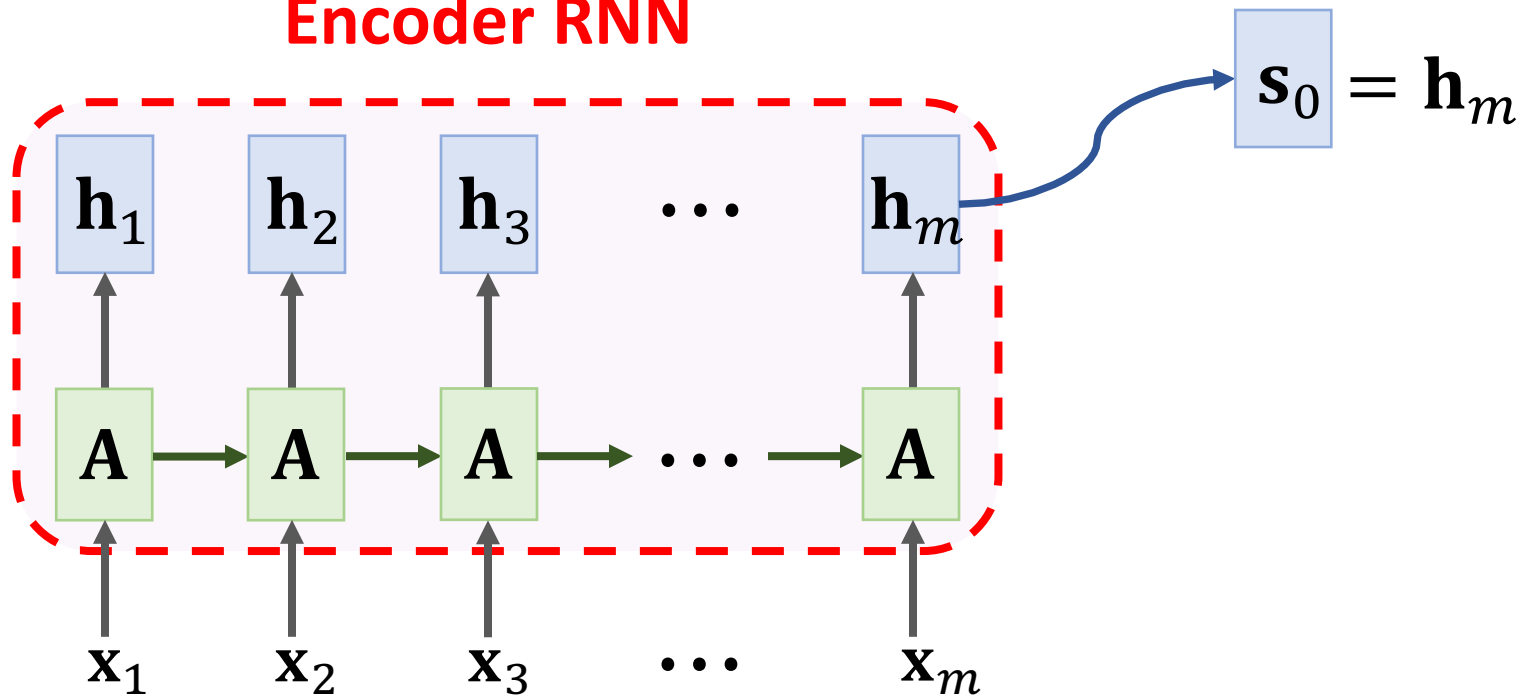
Seq2Seq Model with Attention

Original paper:

- Bahdanau, Cho, & Bengio. [Neural machine translation by jointly learning to align and translate](#). In *ICLR*, 2015.

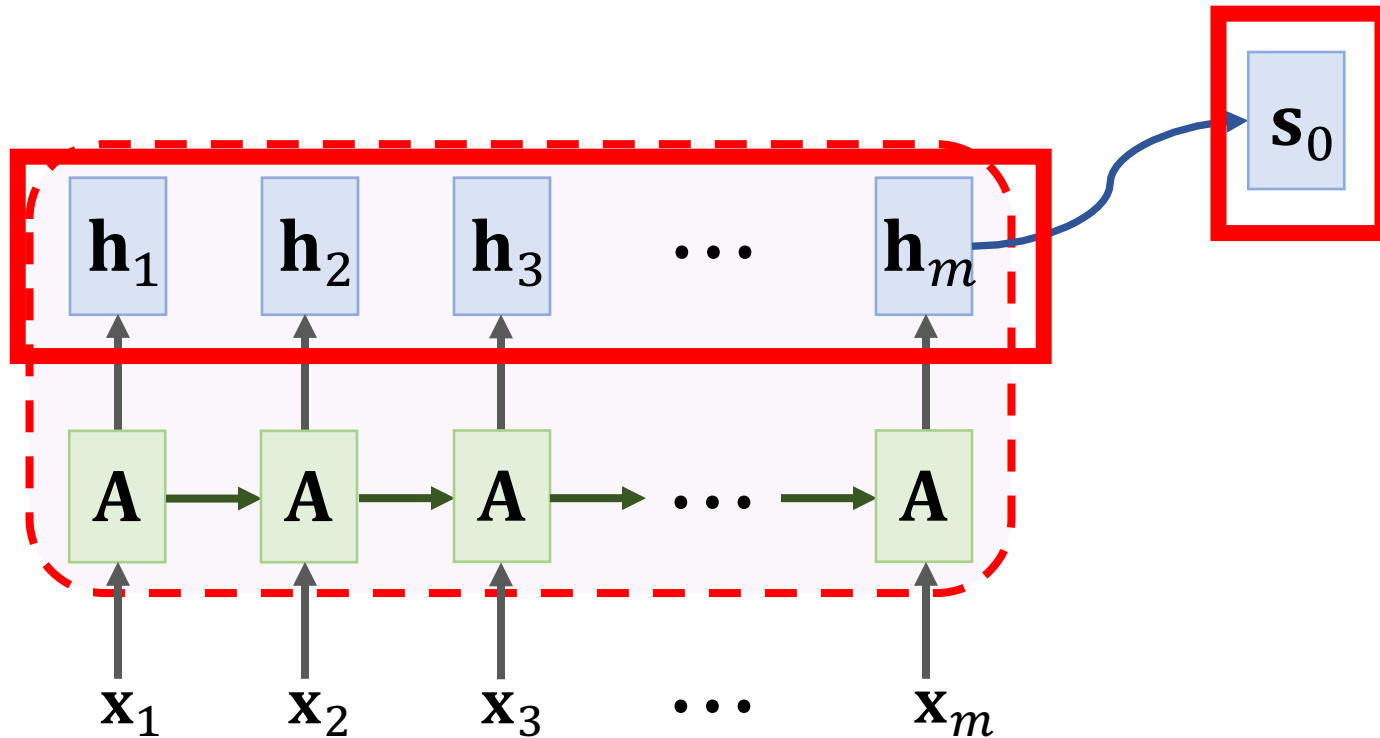
SimpleRNN + Attention

Encoder RNN



SimpleRNN + Attention

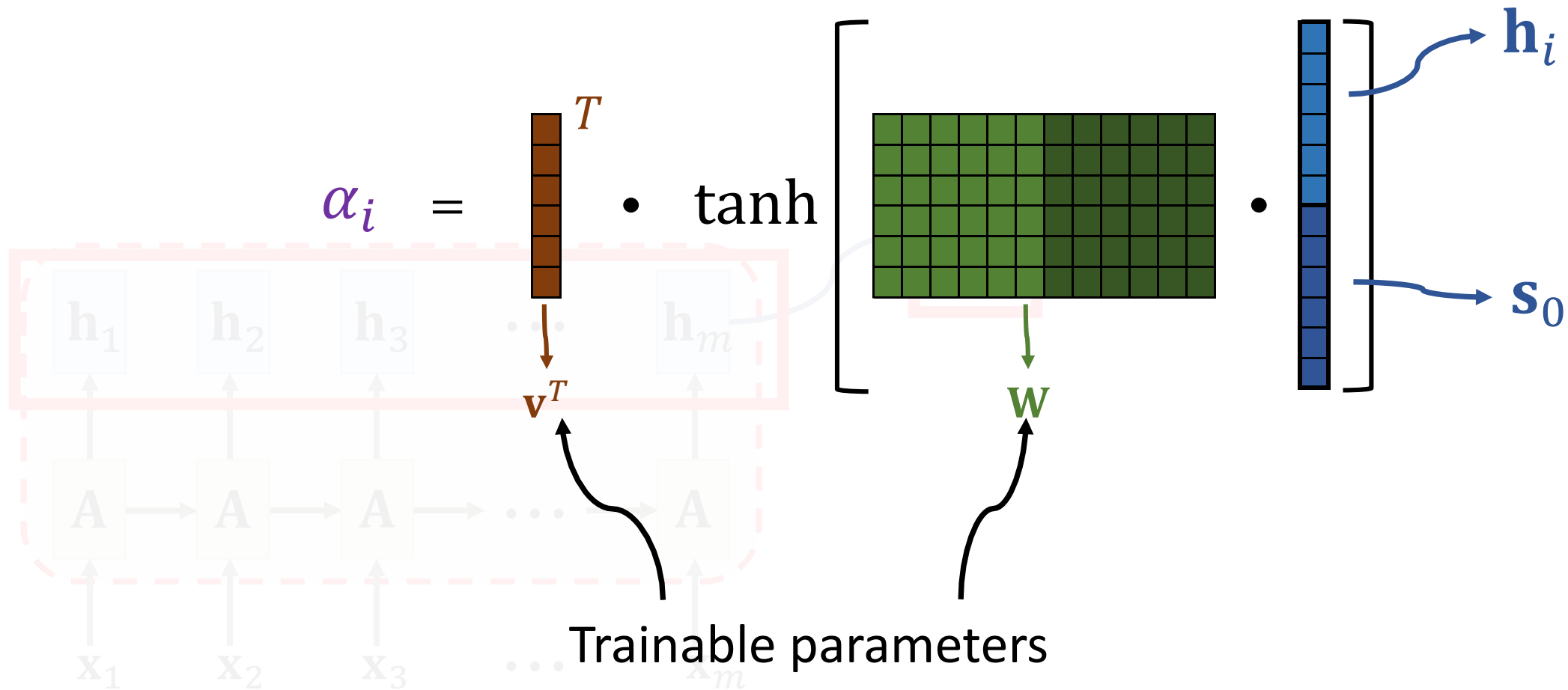
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$



SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$

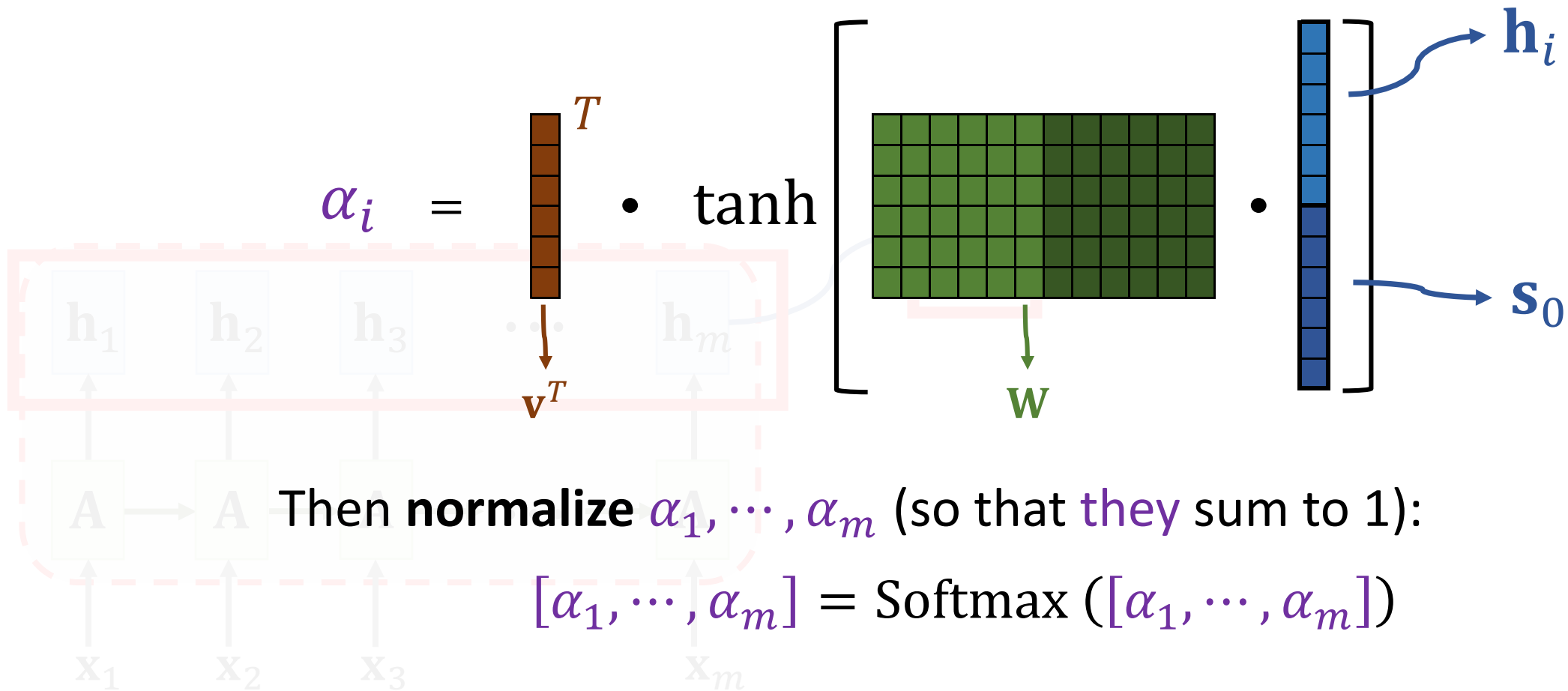
One option (used in the original paper):



SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$

One option (used in the original paper):



SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$

Another option (more popular; the same to Transformer):

1. Linear maps:

- $\tilde{\mathbf{h}}_i = \mathbf{W}_h \cdot \mathbf{h}_i$.
- $\tilde{\mathbf{s}}_0 = \mathbf{W}_s \cdot \mathbf{s}_0$.

2. Inner produce:

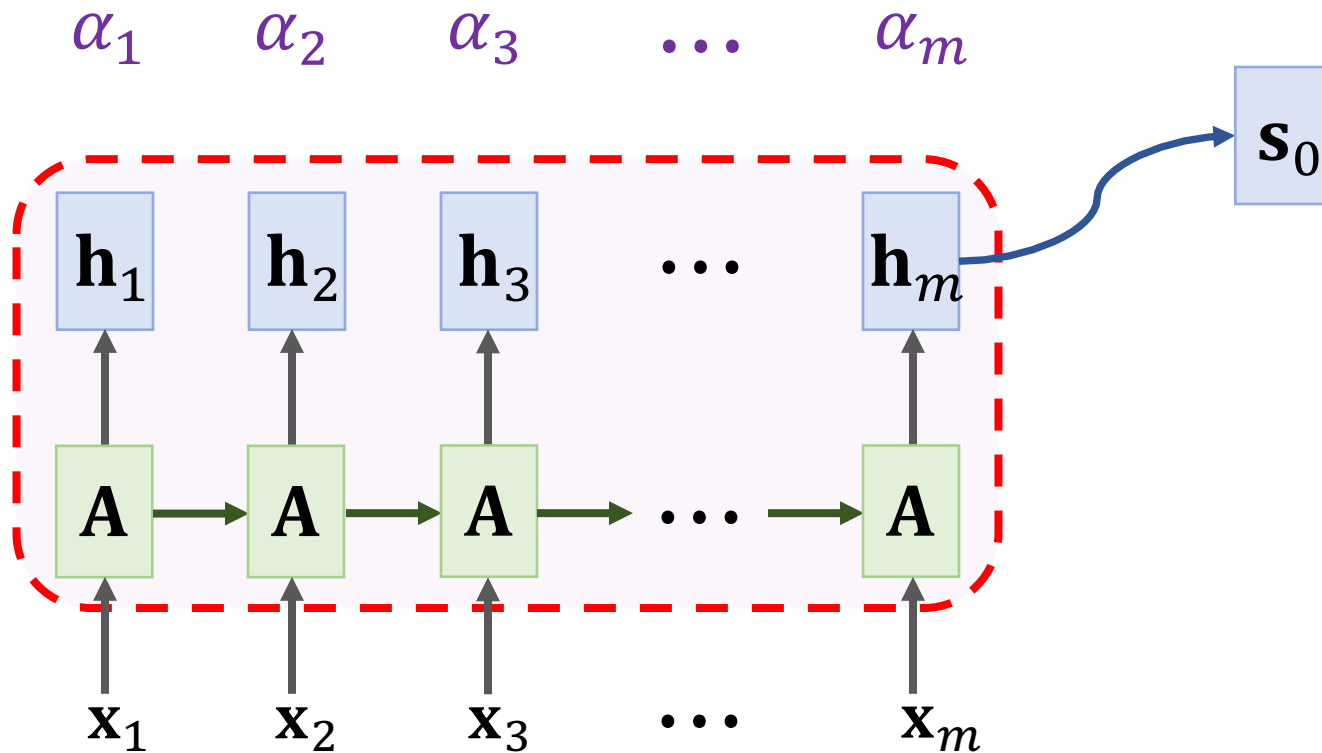
- $\alpha_i = \tilde{\mathbf{h}}_i^T \cdot \tilde{\mathbf{s}}_0$.

3. Normalization:

- $[\alpha_1, \dots, \alpha_m] = \text{Softmax}([\alpha_1, \dots, \alpha_m])$

SimpleRNN + Attention

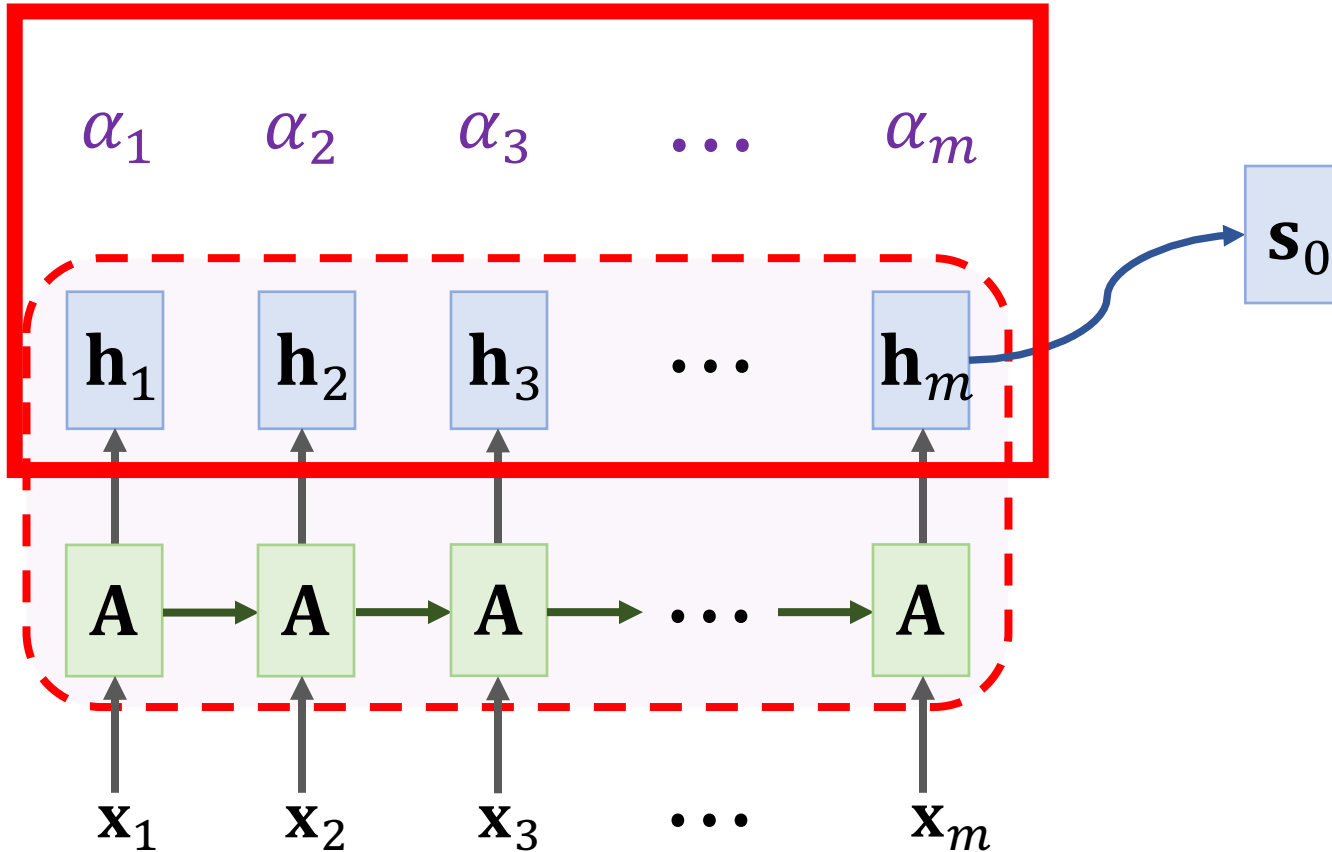
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$



SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$

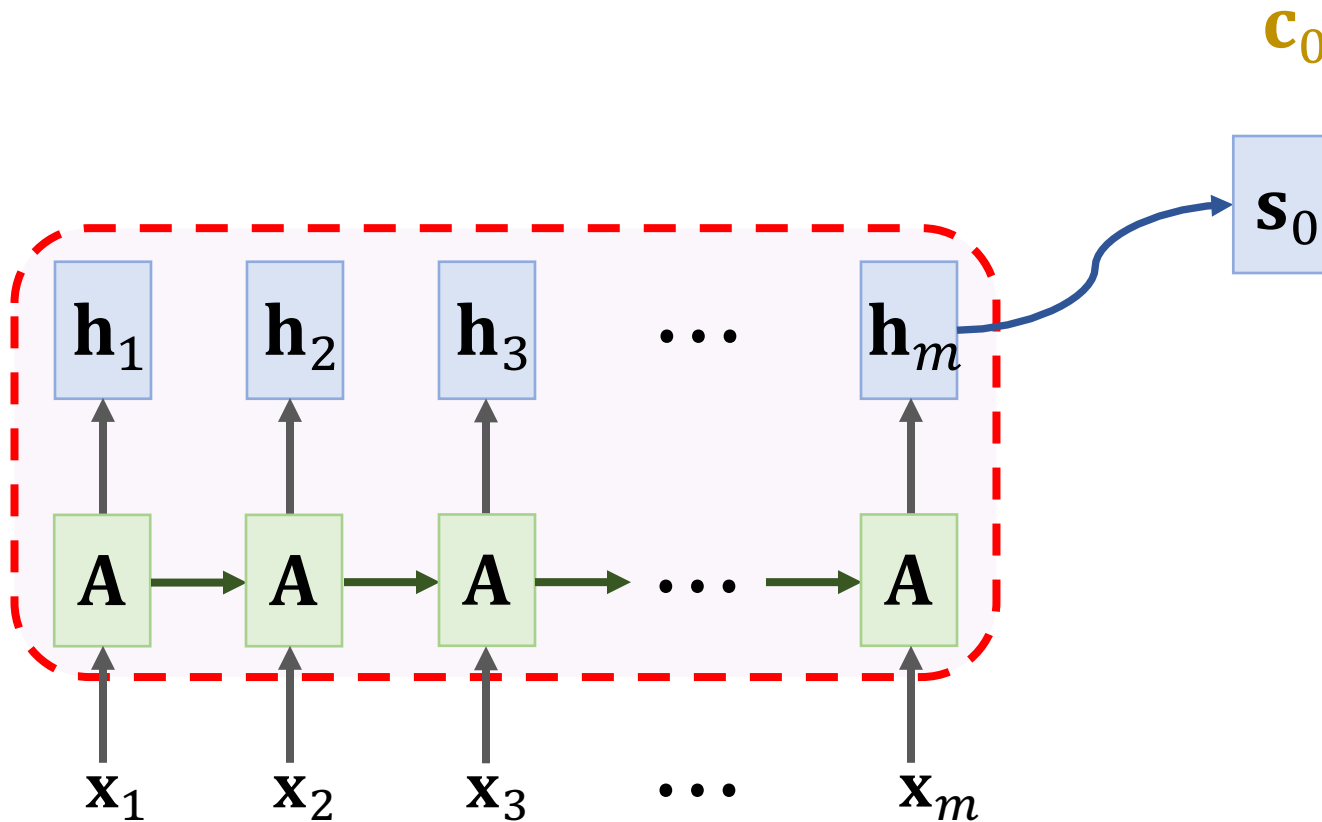
Context vector: $\mathbf{c}_0 = \alpha_1 \mathbf{h}_1 + \dots + \alpha_m \mathbf{h}_m.$



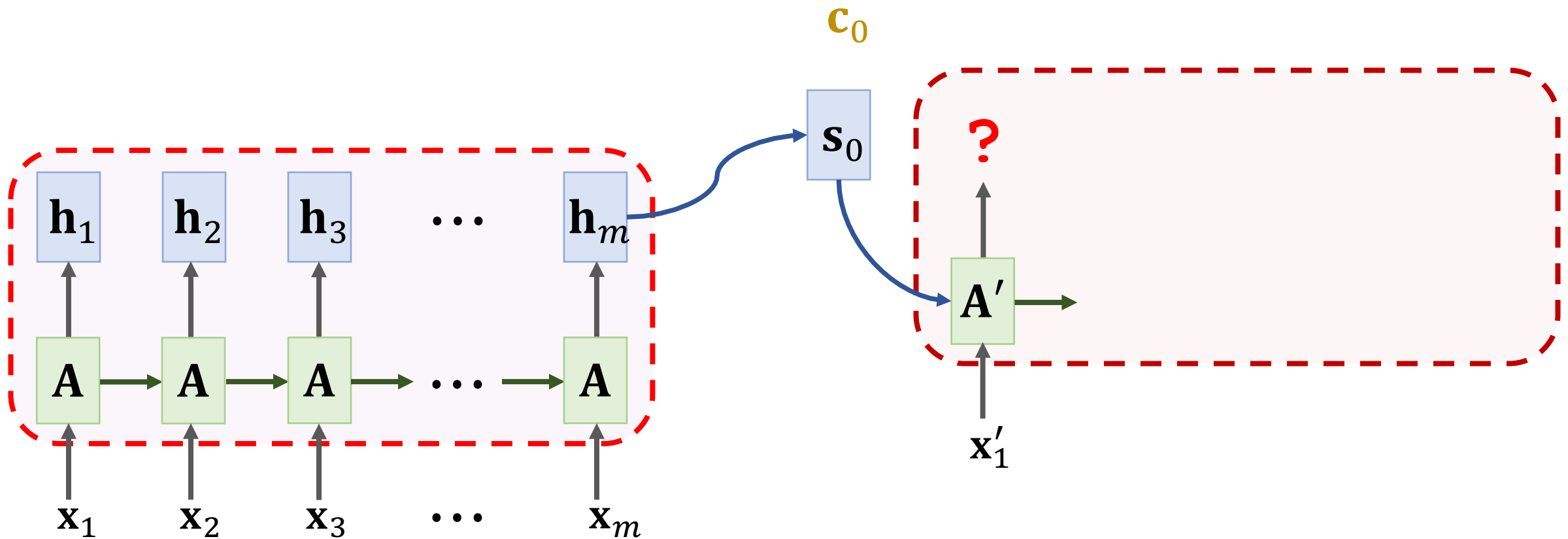
SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_0)$

Context vector: $\mathbf{c}_0 = \alpha_1 \mathbf{h}_1 + \dots + \alpha_m \mathbf{h}_m.$



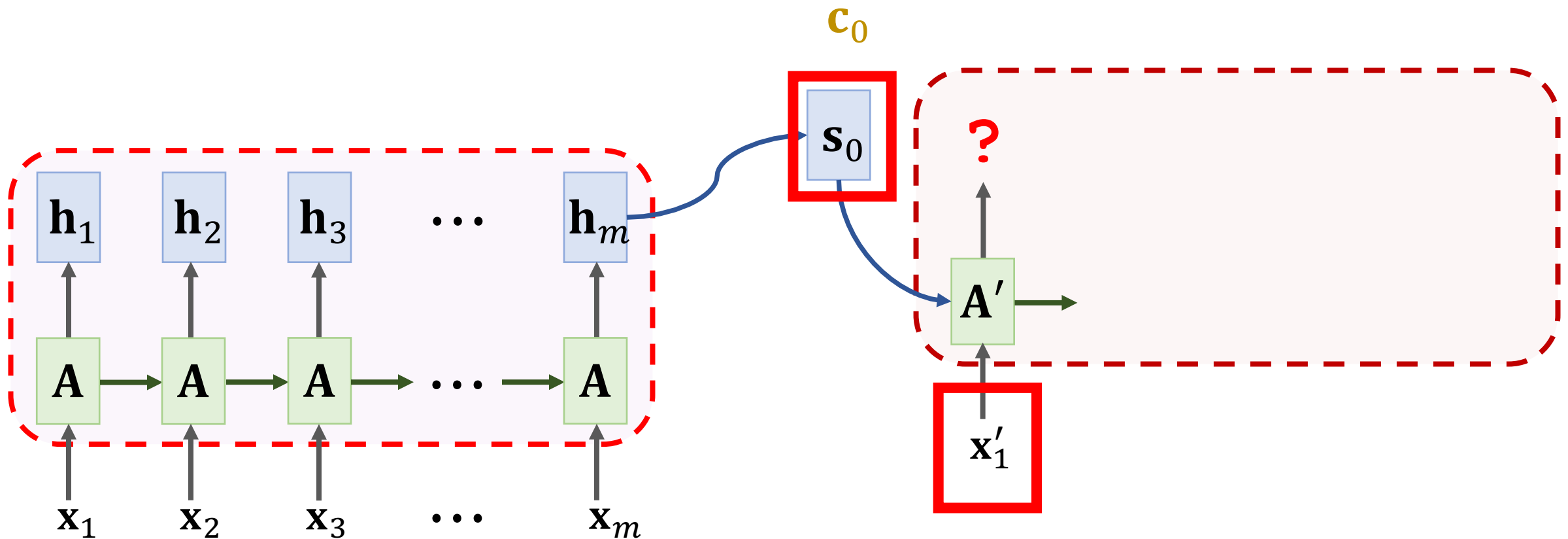
SimpleRNN + Attention



SimpleRNN + Attention

SimpleRNN:

$$\mathbf{s}_1 = \tanh \left(\mathbf{A}' \cdot \begin{bmatrix} \mathbf{x}'_1 \\ \mathbf{s}_0 \end{bmatrix} + \mathbf{b} \right)$$



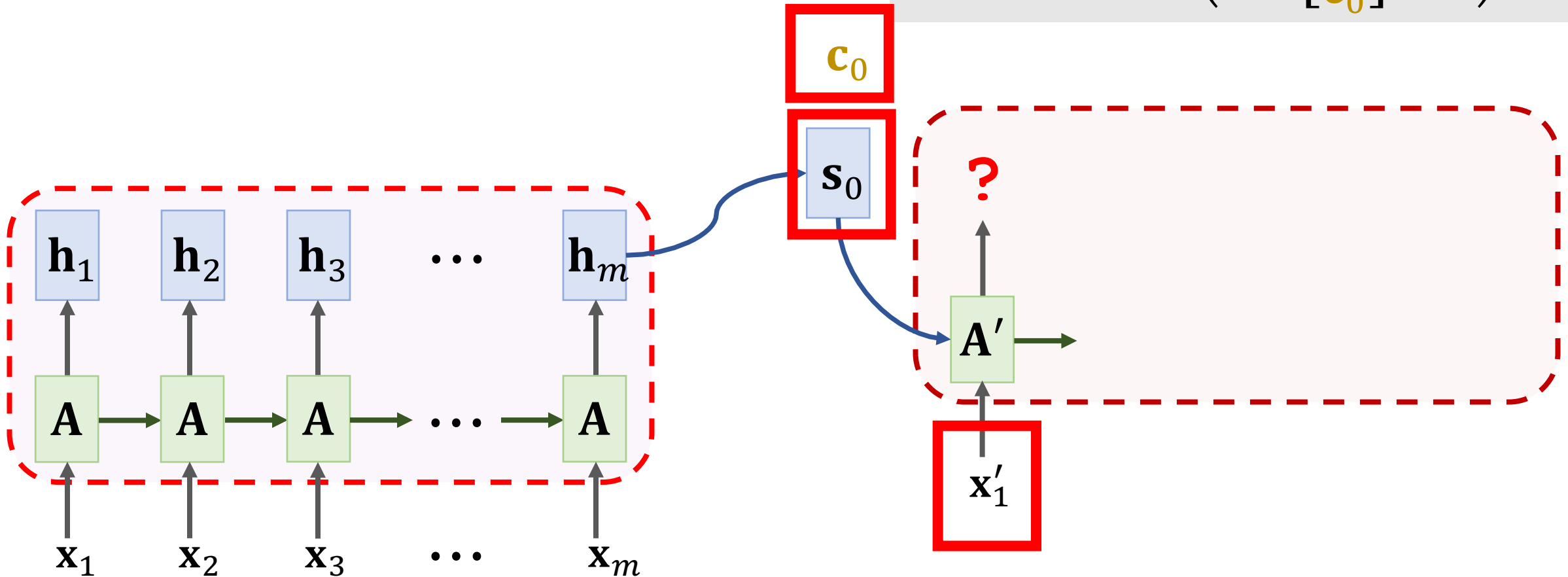
SimpleRNN + Attention

SimpleRNN:

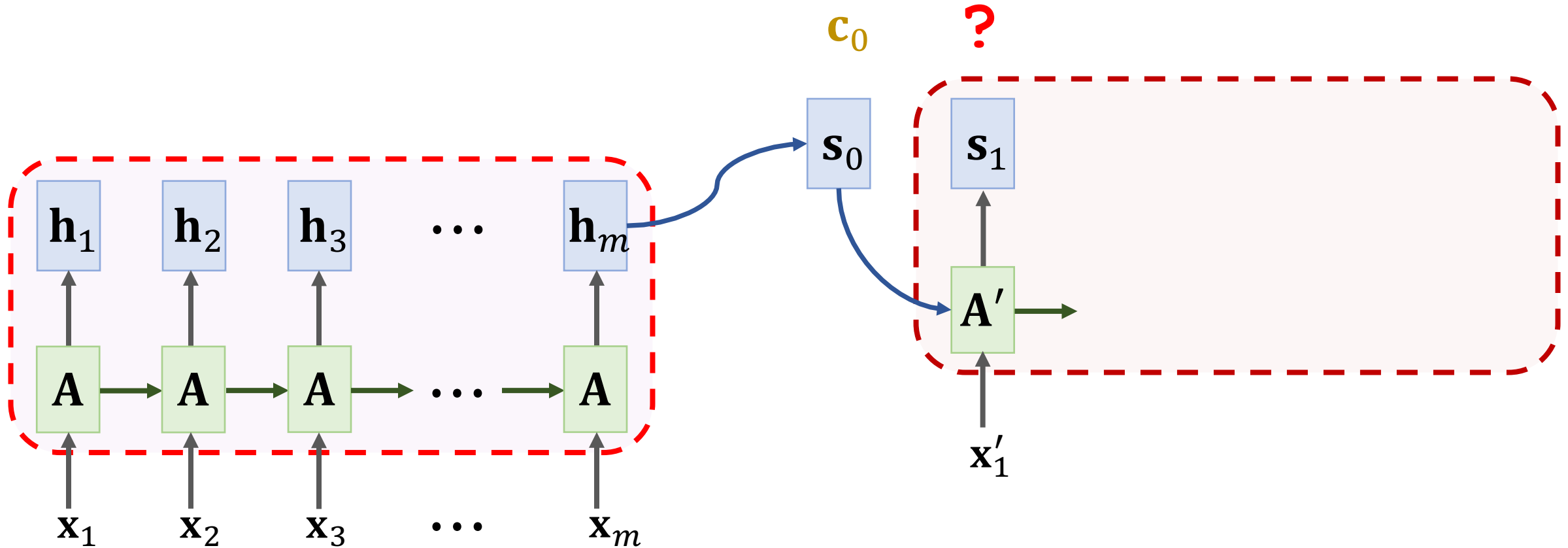
$$\mathbf{s}_1 = \tanh \left(\mathbf{A}' \cdot \begin{bmatrix} \mathbf{x}'_1 \\ \mathbf{s}_0 \end{bmatrix} + \mathbf{b} \right)$$

SimpleRNN + Attention:

$$\mathbf{s}_1 = \tanh \left(\mathbf{A}' \cdot \begin{bmatrix} \mathbf{x}'_1 \\ \mathbf{s}_0 \\ \mathbf{c}_0 \end{bmatrix} + \mathbf{b} \right)$$

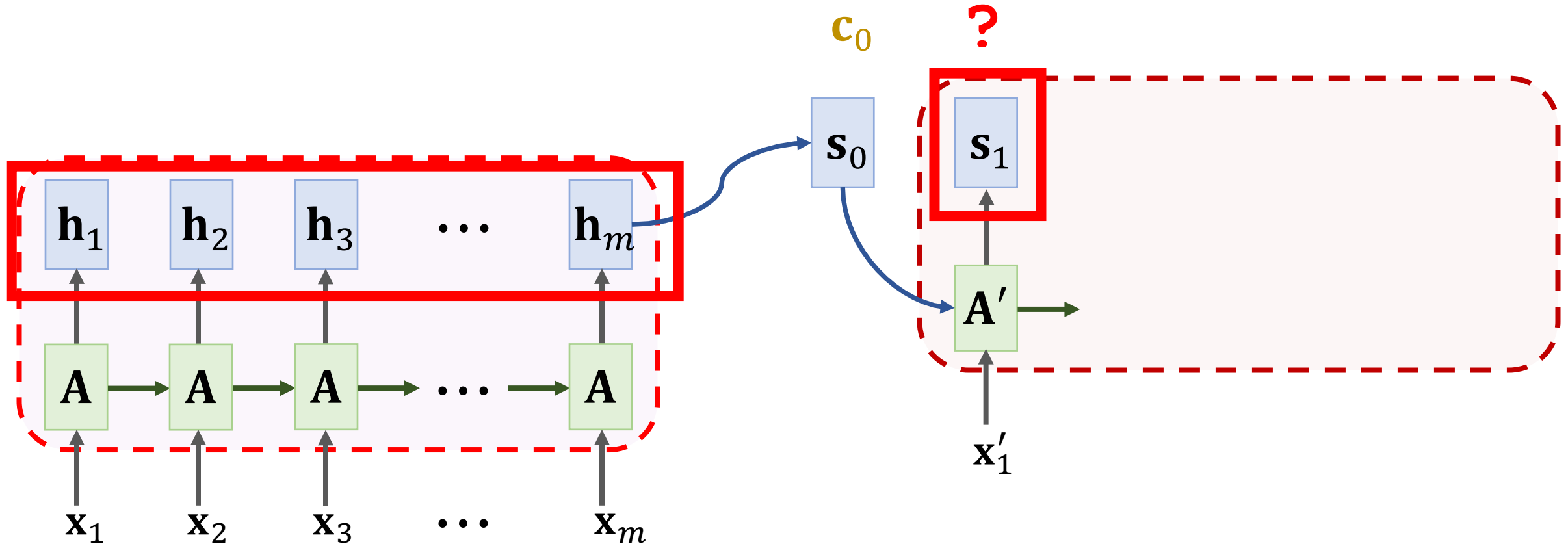


SimpleRNN + Attention



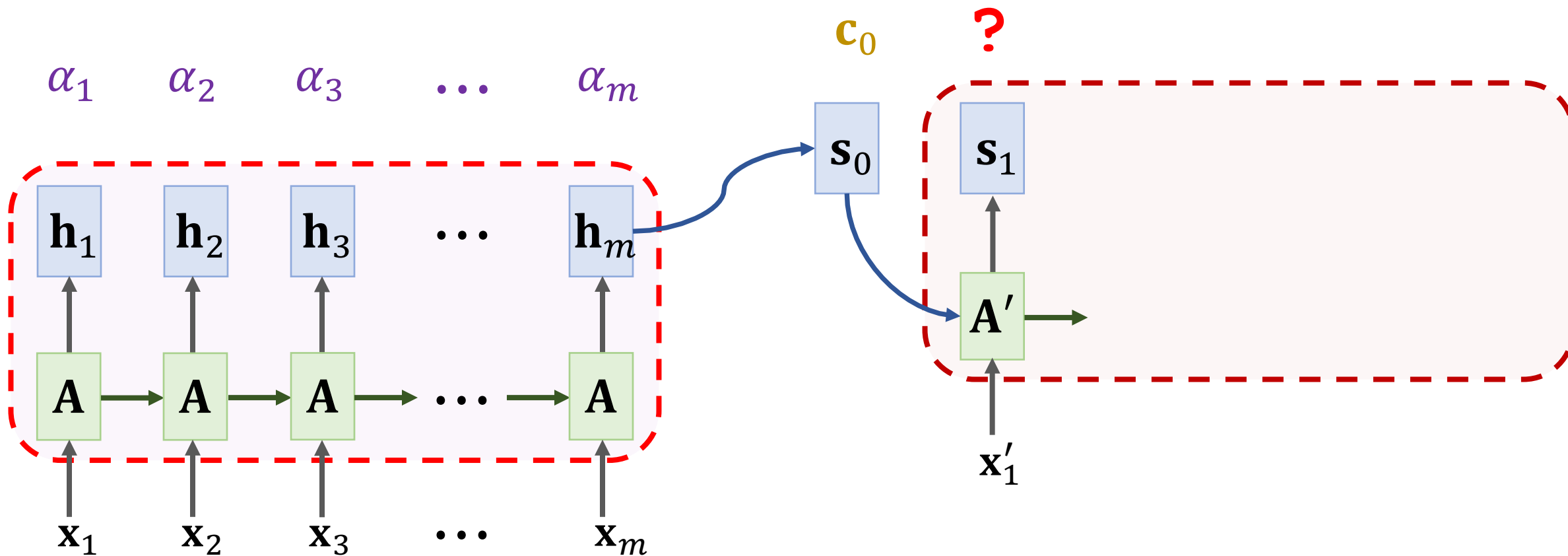
SimpleRNN + Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_1)$



SimpleRNN + Attention

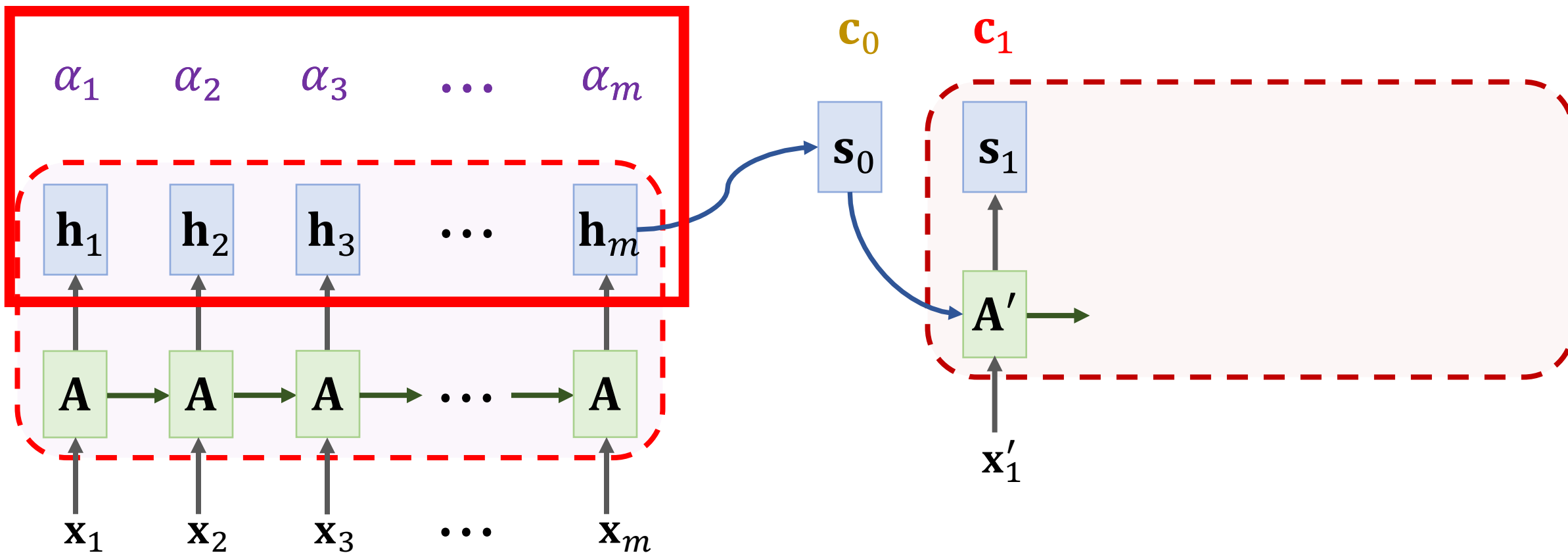
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_1)$



SimpleRNN + Attention

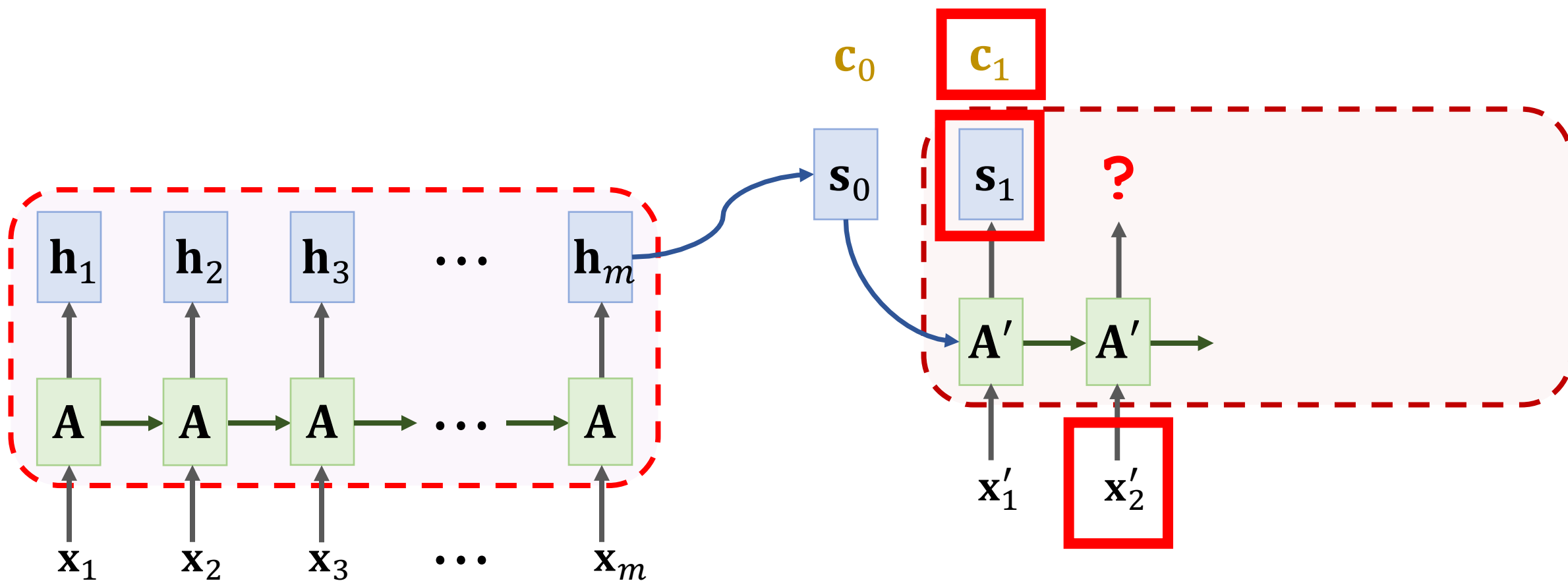
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{s}_1)$

Context vector: $\mathbf{c}_1 = \alpha_1 \mathbf{h}_1 + \dots + \alpha_m \mathbf{h}_m$.

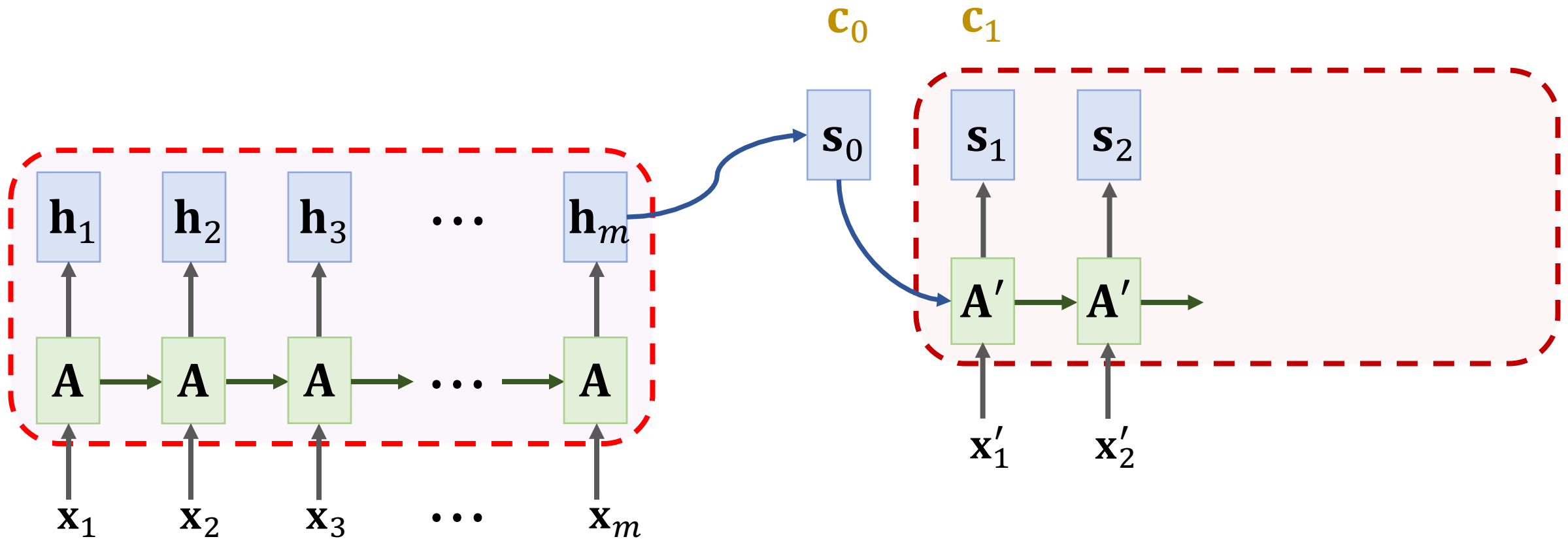


SimpleRNN + Attention

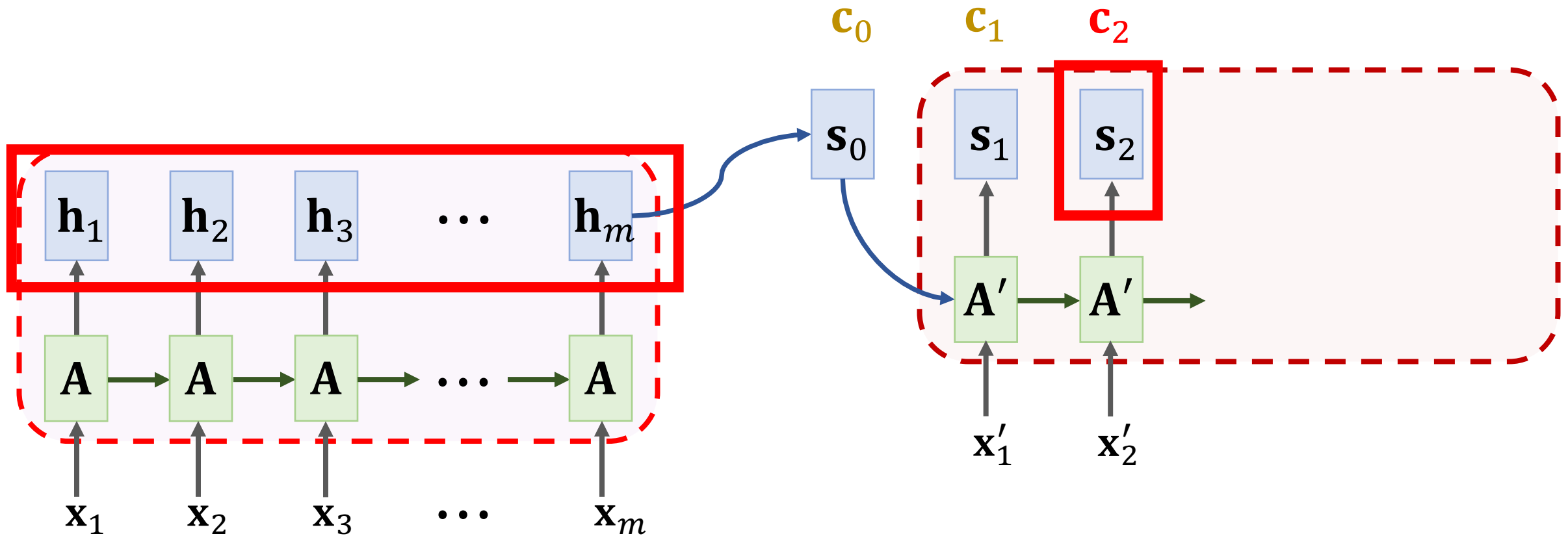
$$\mathbf{s}_2 = \tanh \left(\mathbf{A}' \cdot \begin{bmatrix} \mathbf{x}'_2 \\ \mathbf{s}_1 \\ \mathbf{c}_1 \end{bmatrix} + \mathbf{b} \right)$$



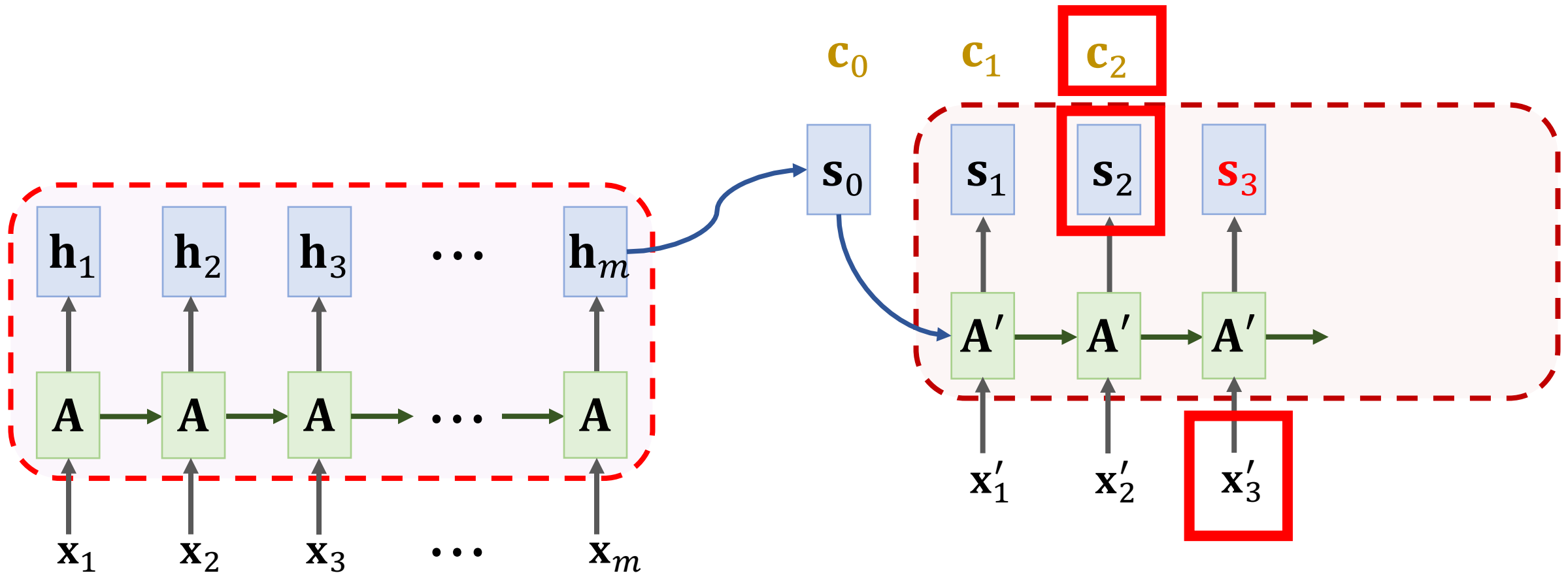
SimpleRNN + Attention



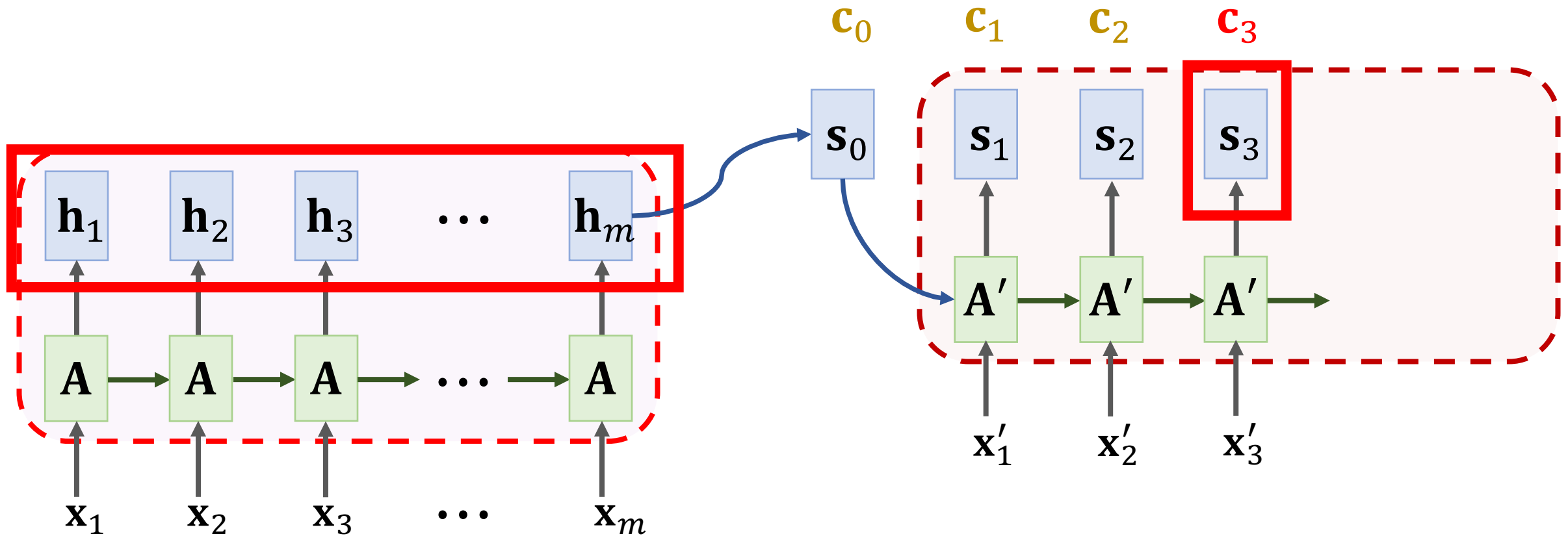
SimpleRNN + Attention



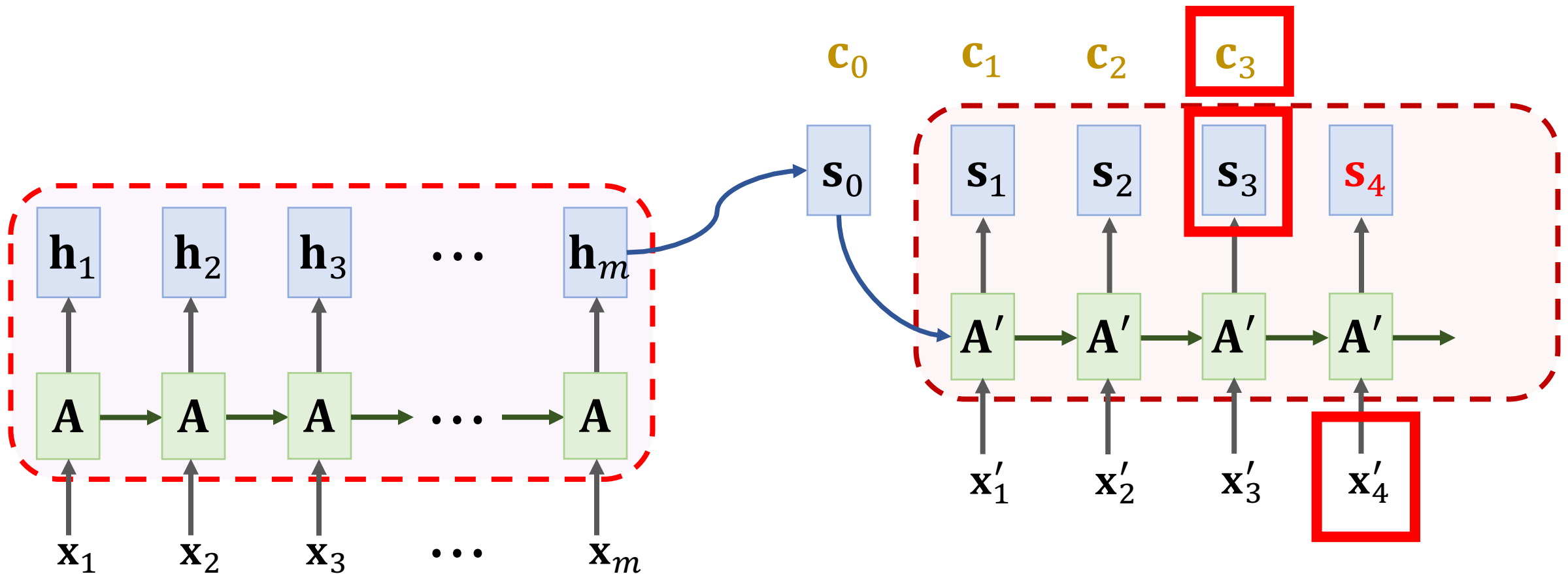
SimpleRNN + Attention



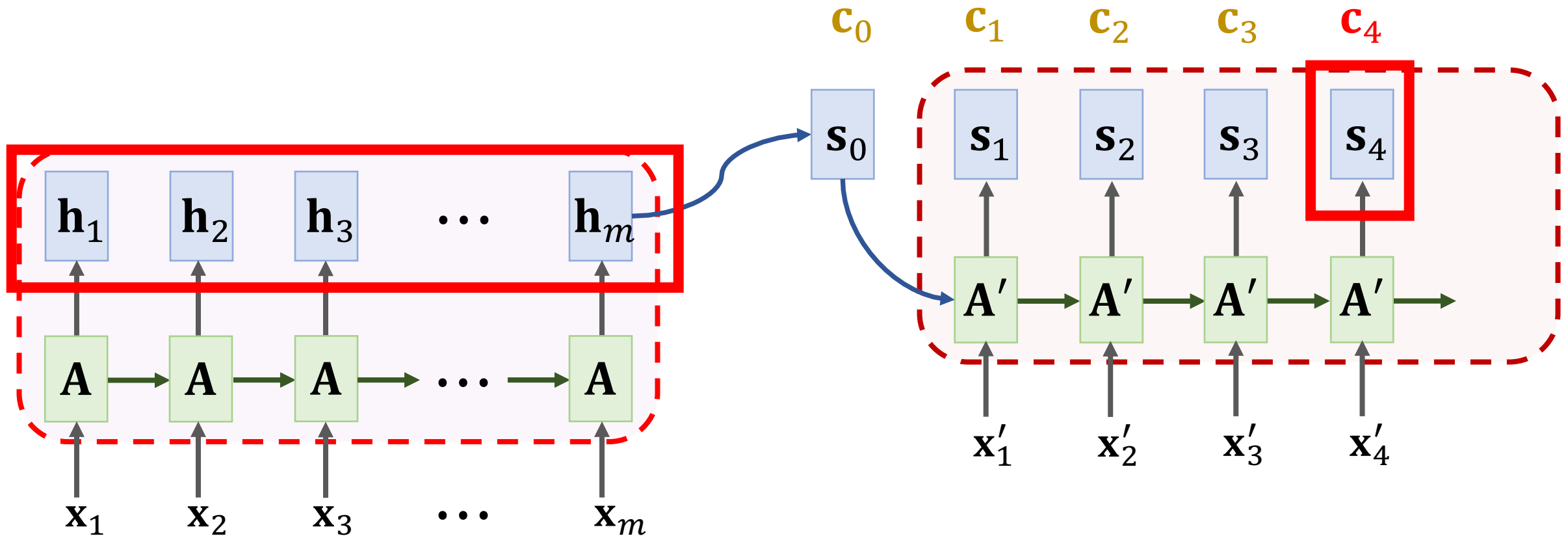
SimpleRNN + Attention



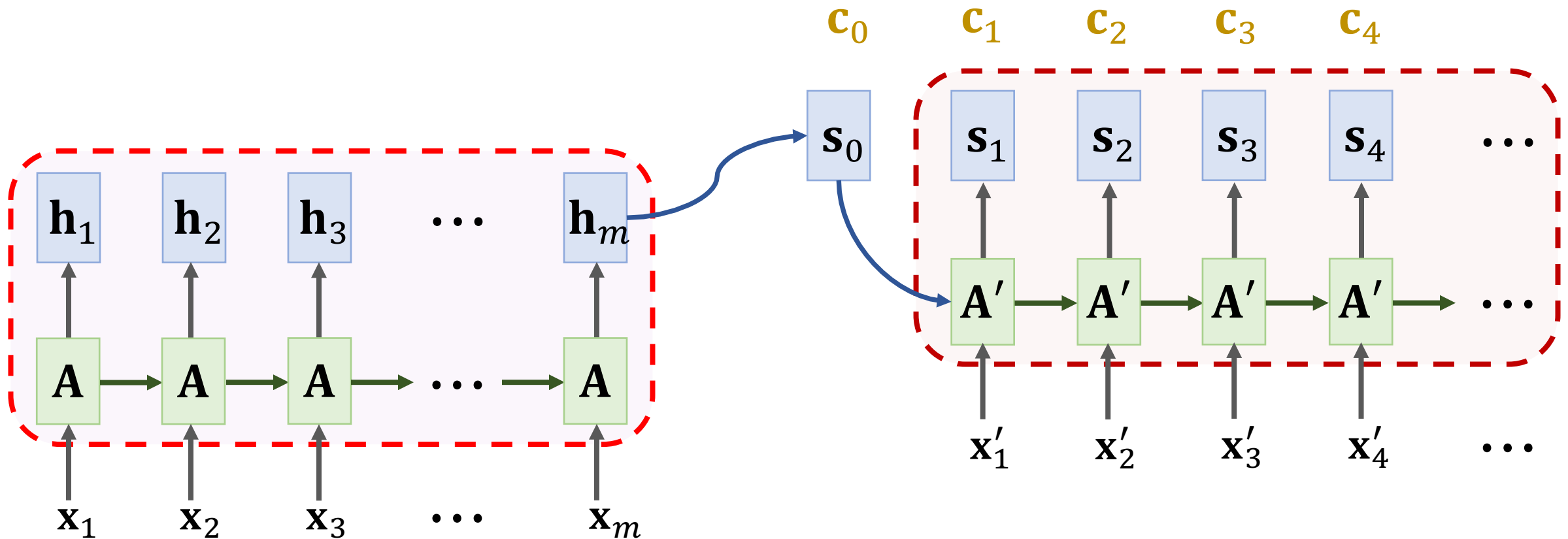
SimpleRNN + Attention



SimpleRNN + Attention

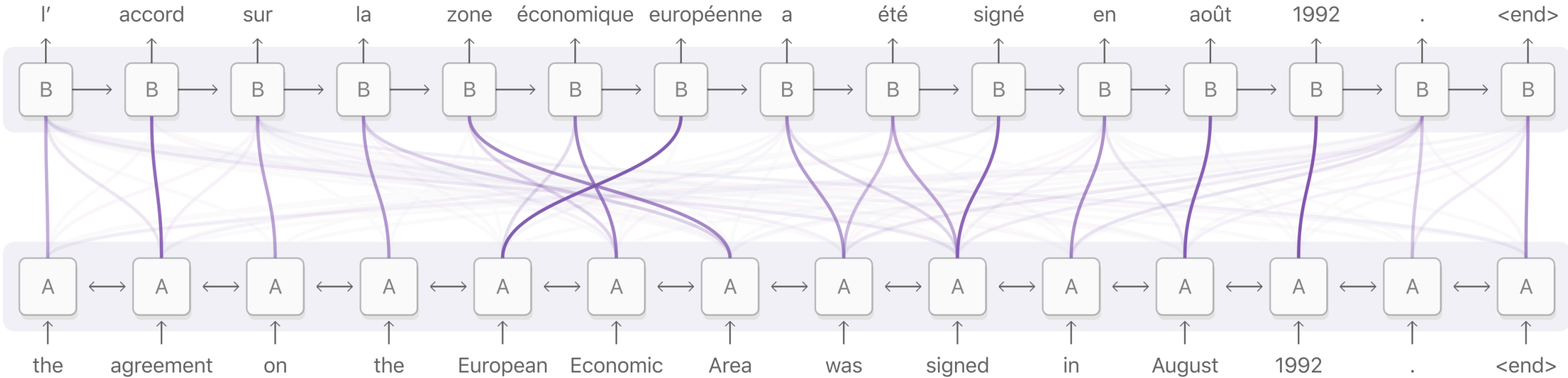


SimpleRNN + Attention



Attention: Weights Visualization

Decoder RNN

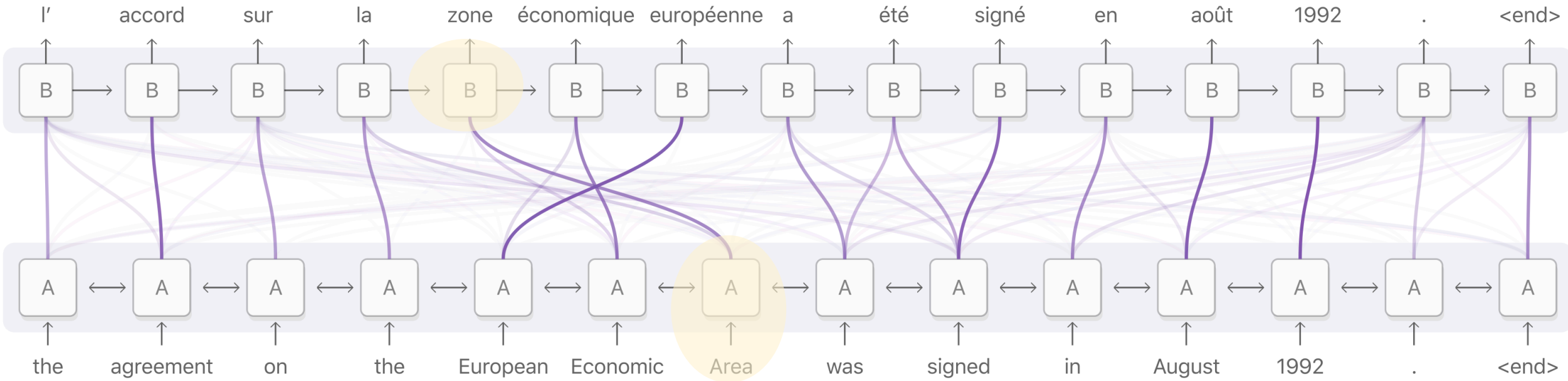


Encoder RNN

Figure is from <https://distill.pub/2016/augmented-rnns/>

Attention: Weights Visualization

Decoder RNN

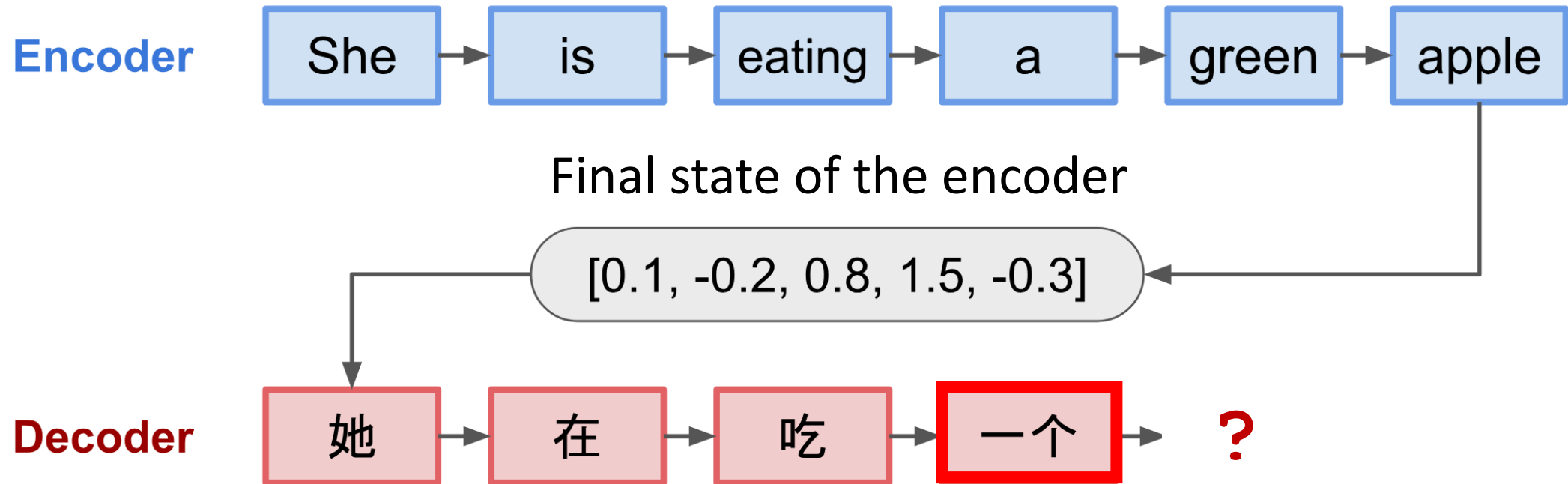


Encoder RNN

Figure is from <https://distill.pub/2016/augmented-rnns/>

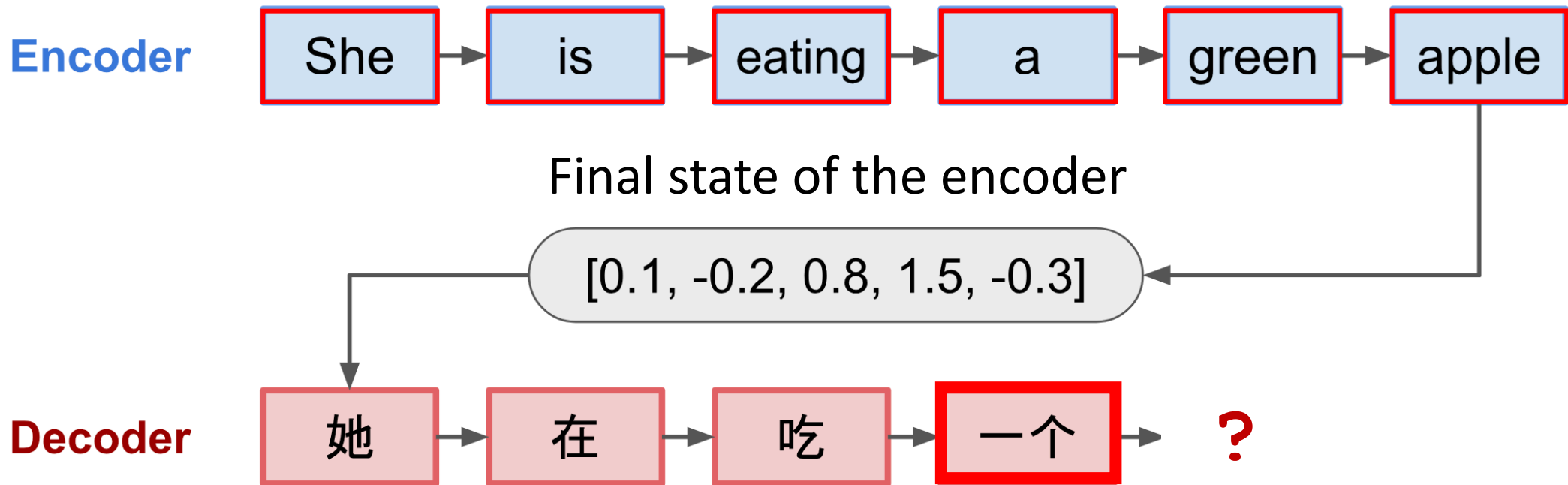
Summary

- Standard Seq2Seq model: the decoder looks at only **its current state**.



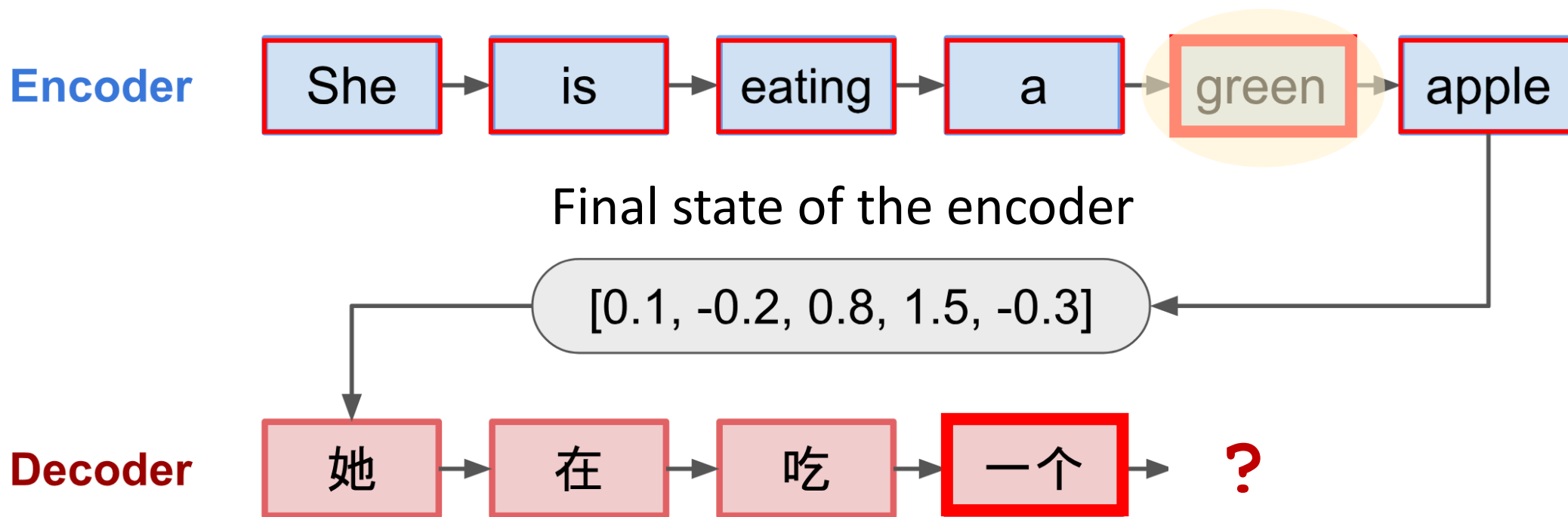
Summary

- Standard Seq2Seq model: the decoder looks at only its current state.
- Attention: decoder additionally looks at **all the states of the encoder**.



Summary

- Standard Seq2Seq model: the decoder looks at only its current state.
- Attention: decoder additionally looks at **all the states of the encoder**.



Summary

- Standard Seq2Seq model: the decoder looks at only its current state.
- Attention: decoder additionally looks at all the states of the encoder.
- Downside: higher time complexity.
 - l_1 : source sequence length
 - l_2 : target sequence length
 - Standard Seq2Seq: $O(l_1 + l_2)$ time complexity
 - Seq2Seq + attention: $O(l_1 l_2)$ time complexity


Self-Attention: Attention beyond Seq2Seq Models

Original paper:

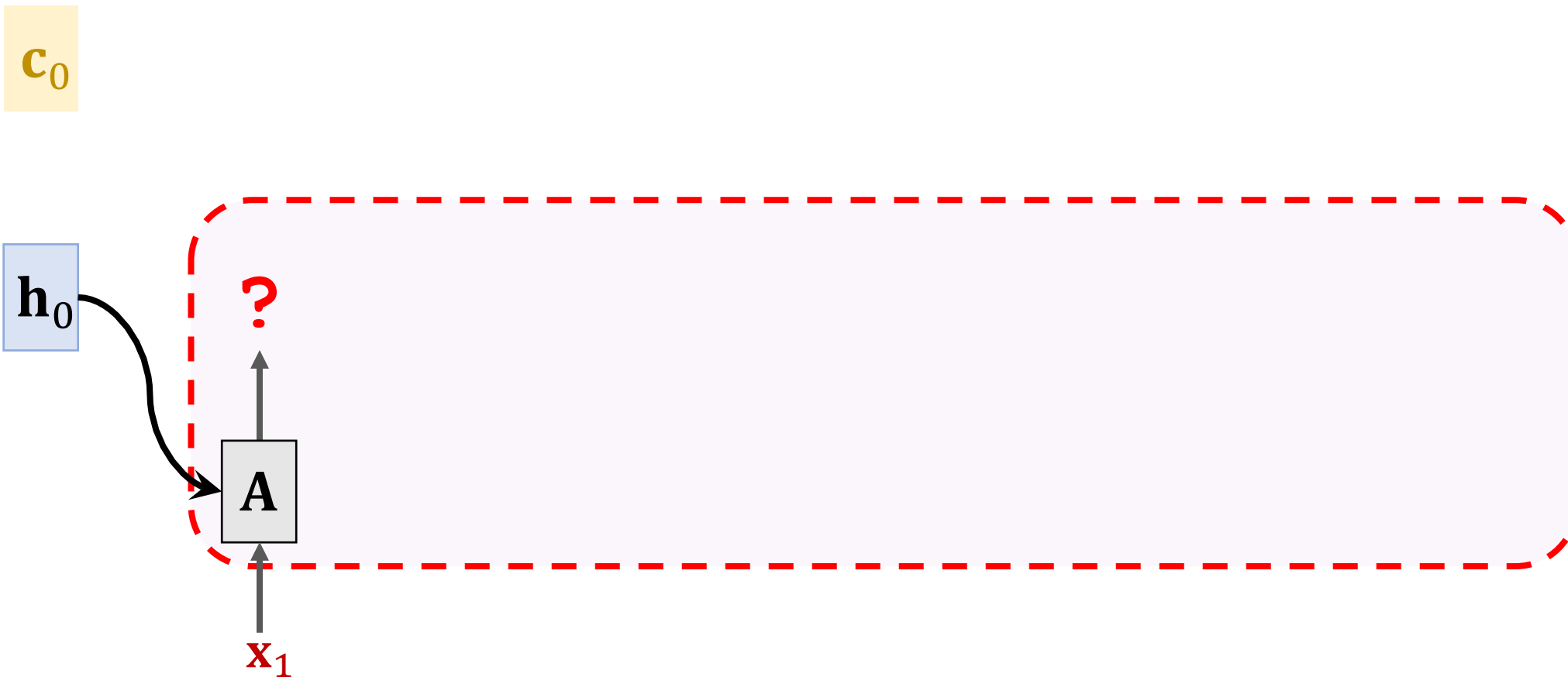
- Cheng, Dong, & Lapata. [Long Short-Term Memory-Networks for Machine Reading](#). In *EMNLP*, 2016.

SimpleRNN + Self-Attention

$$\mathbf{c}_0 = \mathbf{0}$$

$$\mathbf{h}_0 = \mathbf{0}$$


SimpleRNN + Self-Attention



SimpleRNN + Self-Attention

SimpleRNN:

$$\mathbf{h}_1 = \tanh \left(\mathbf{A} \cdot \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{h}_0 \end{bmatrix} + \mathbf{b} \right)$$

\mathbf{c}_0



SimpleRNN + Self-Attention

SimpleRNN:

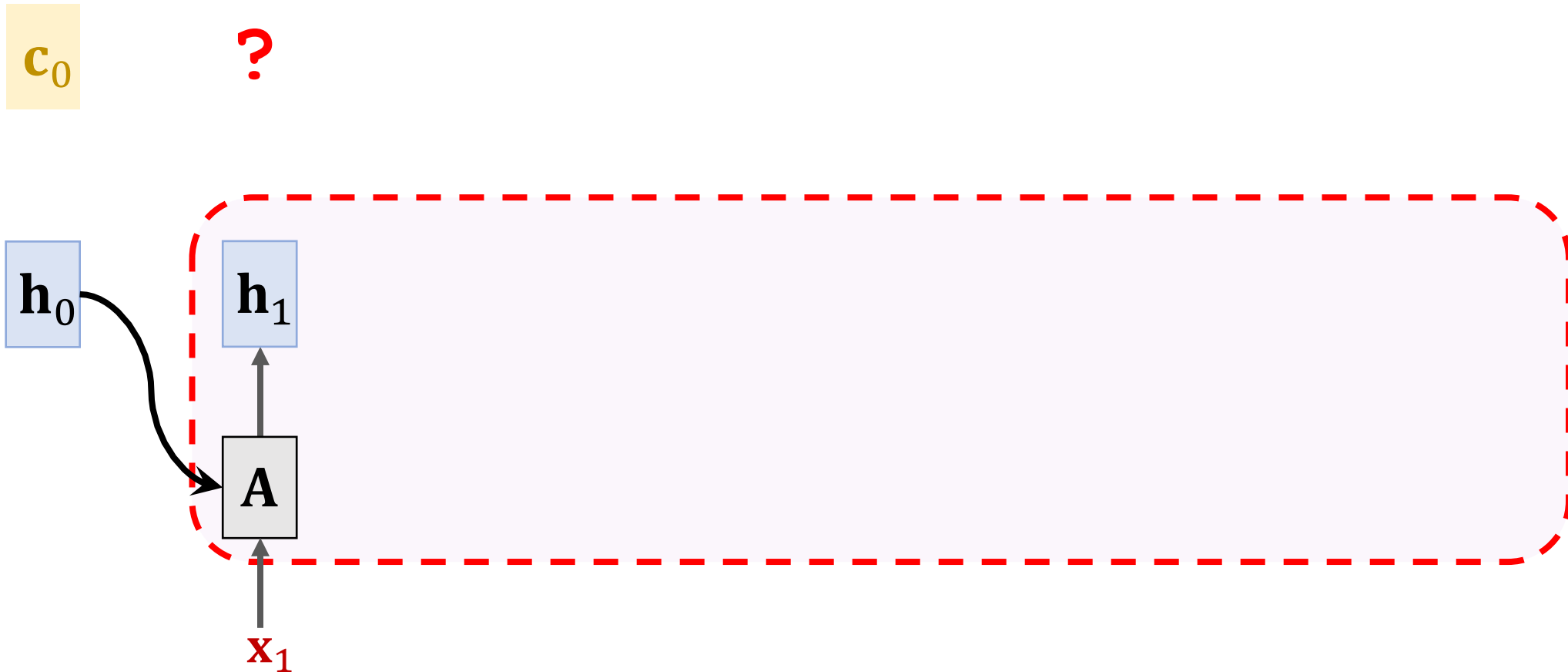
$$\mathbf{h}_1 = \tanh \left(\mathbf{A} \cdot \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{h}_0 \end{bmatrix} + \mathbf{b} \right)$$

SimpleRNN + Self-Attention:

$$\mathbf{h}_1 = \tanh \left(\mathbf{A} \cdot \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{c}_0 \end{bmatrix} + \mathbf{b} \right)$$

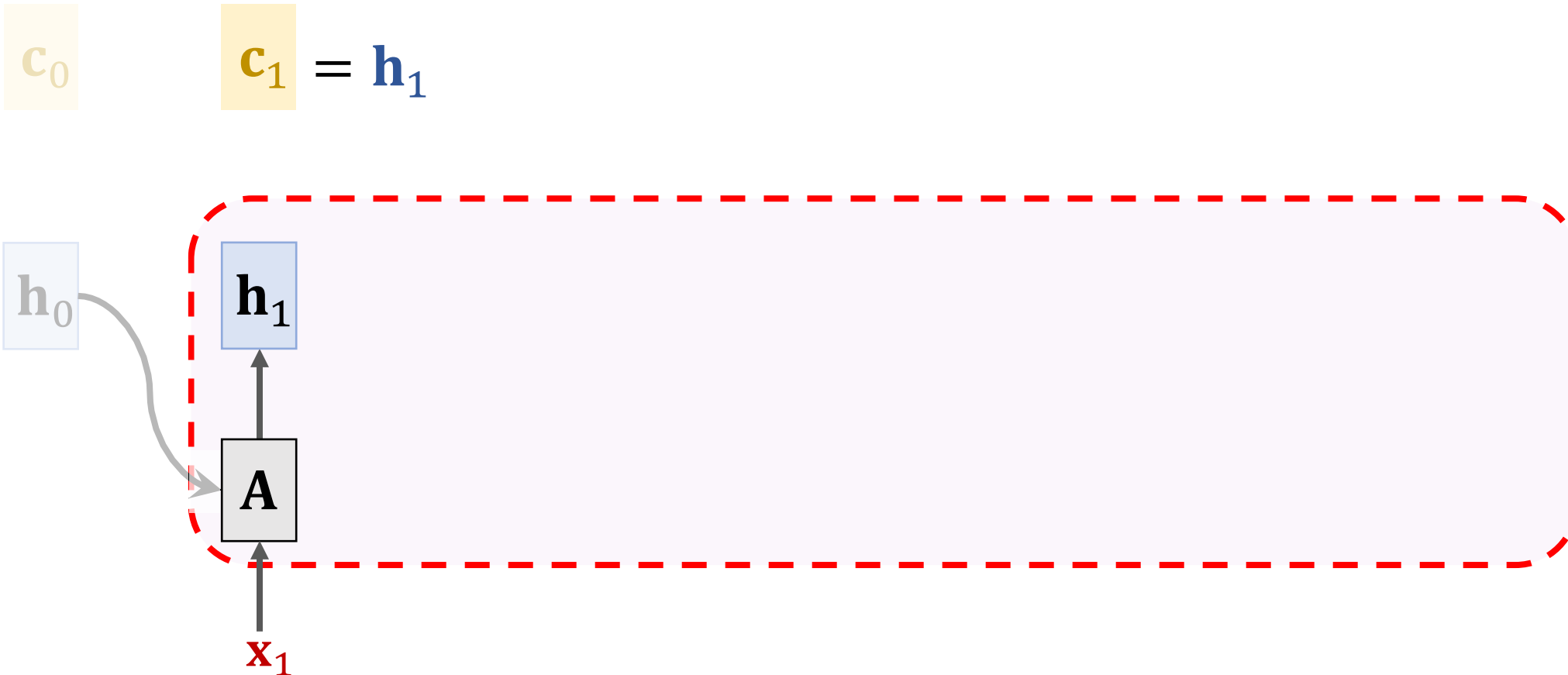


SimpleRNN + Self-Attention



SimpleRNN + Self-Attention

First context vector: $\mathbf{c}_1 = \mathbf{h}_1$.

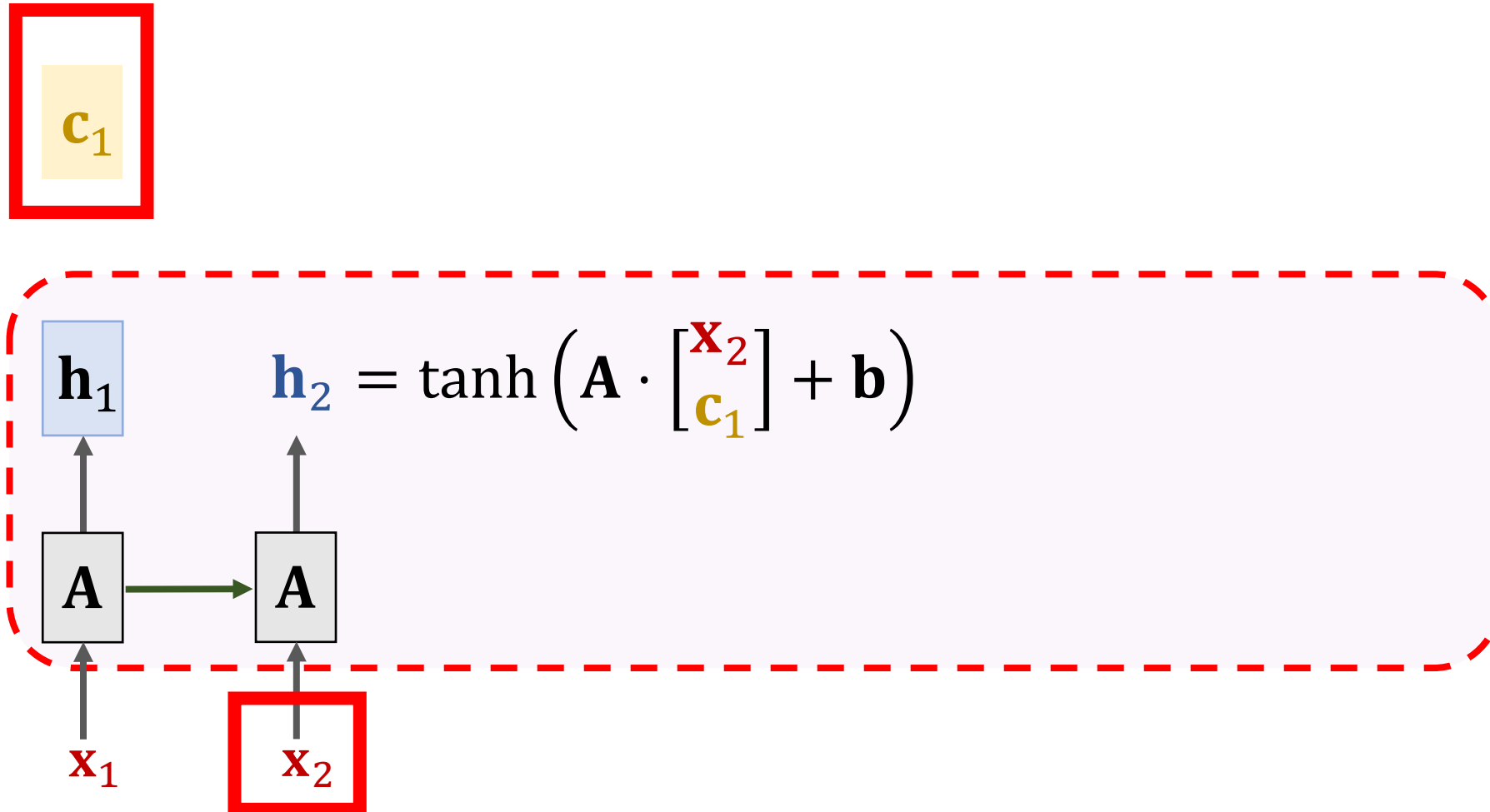


SimpleRNN + Self-Attention

c_1



SimpleRNN + Self-Attention



SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_1)$

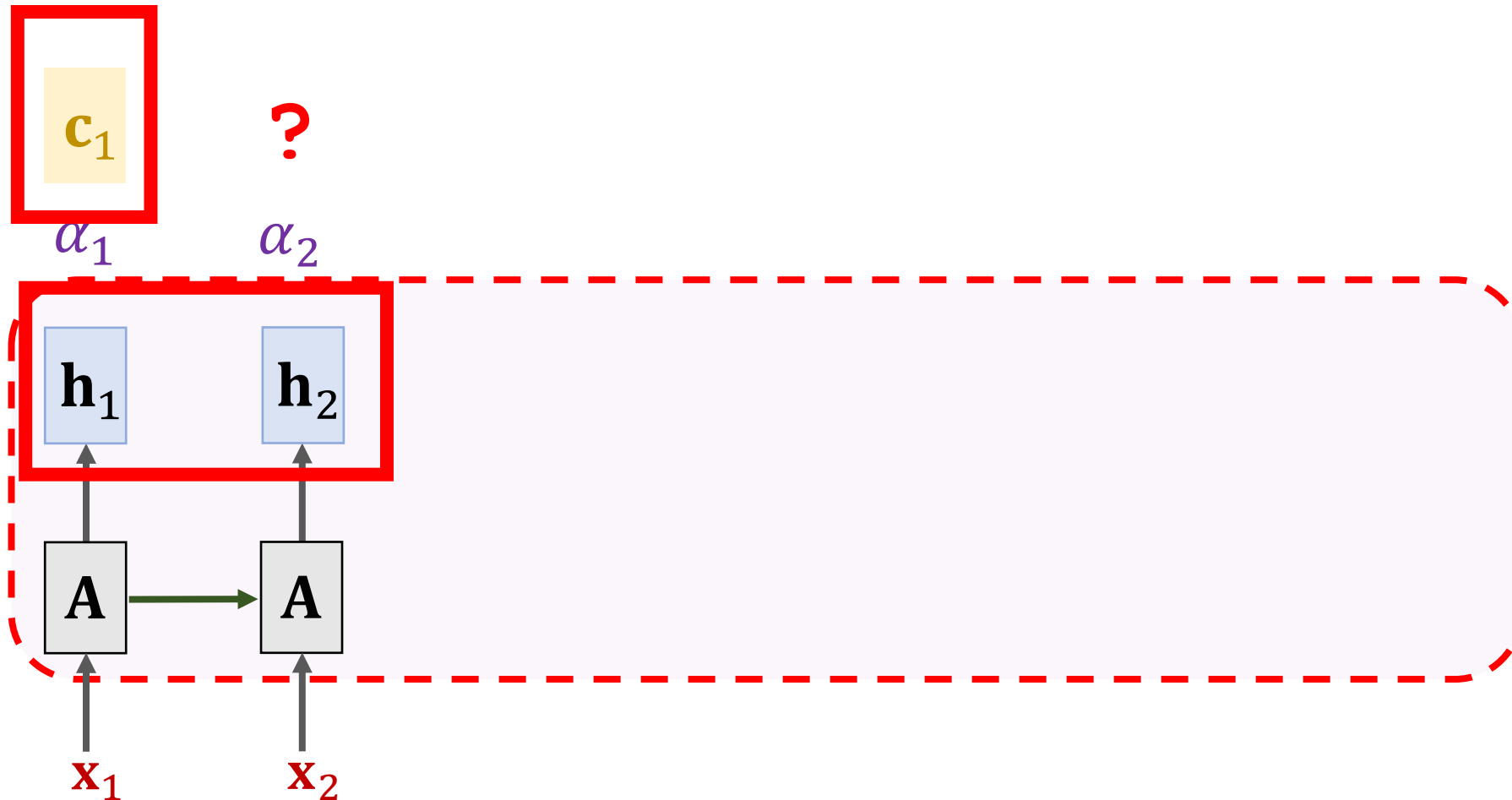
\mathbf{c}_1

?



SimpleRNN + Self-Attention

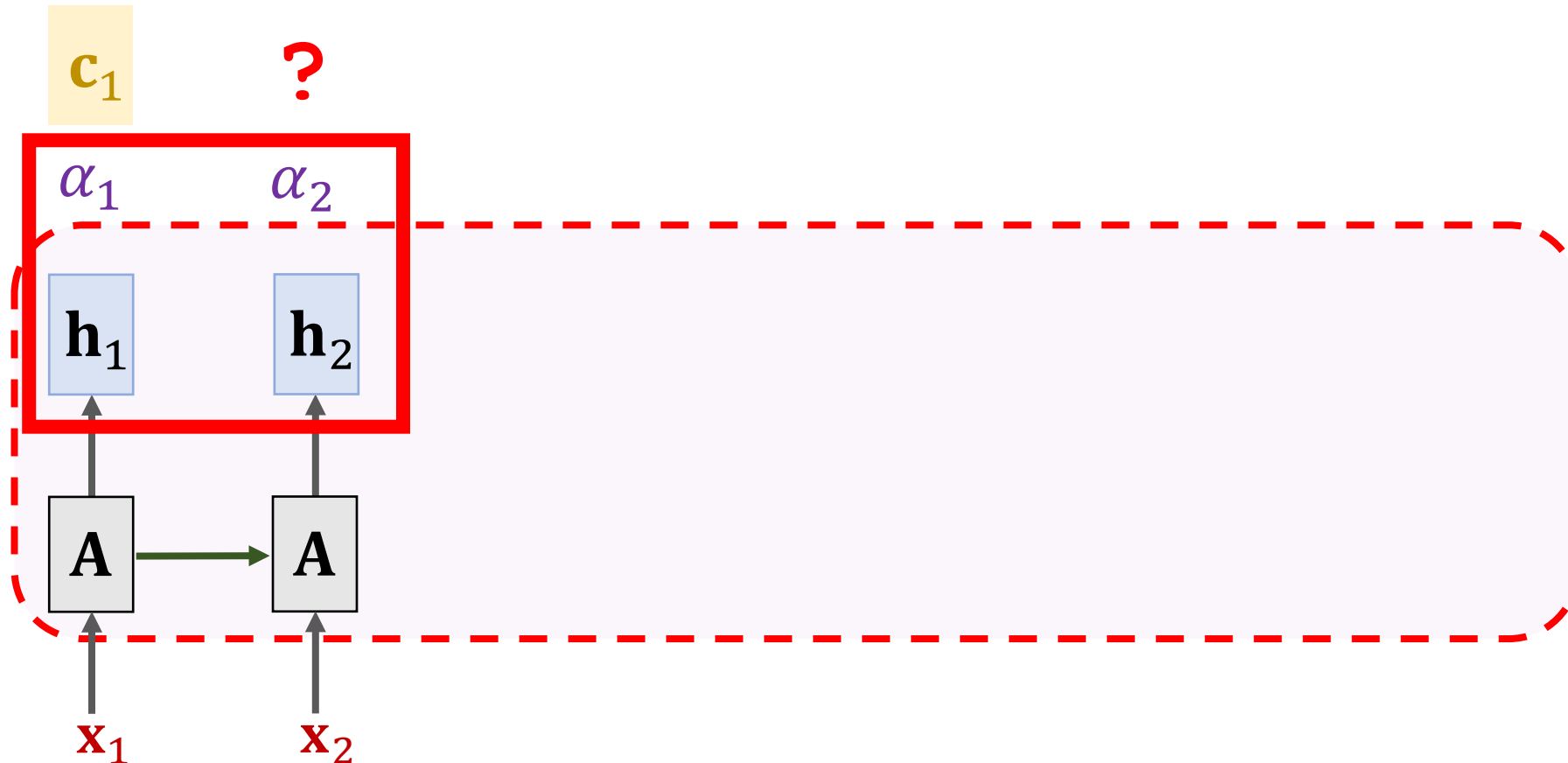
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_1)$



SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_1)$

Context vector: $\mathbf{c}_2 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2.$



SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_1)$

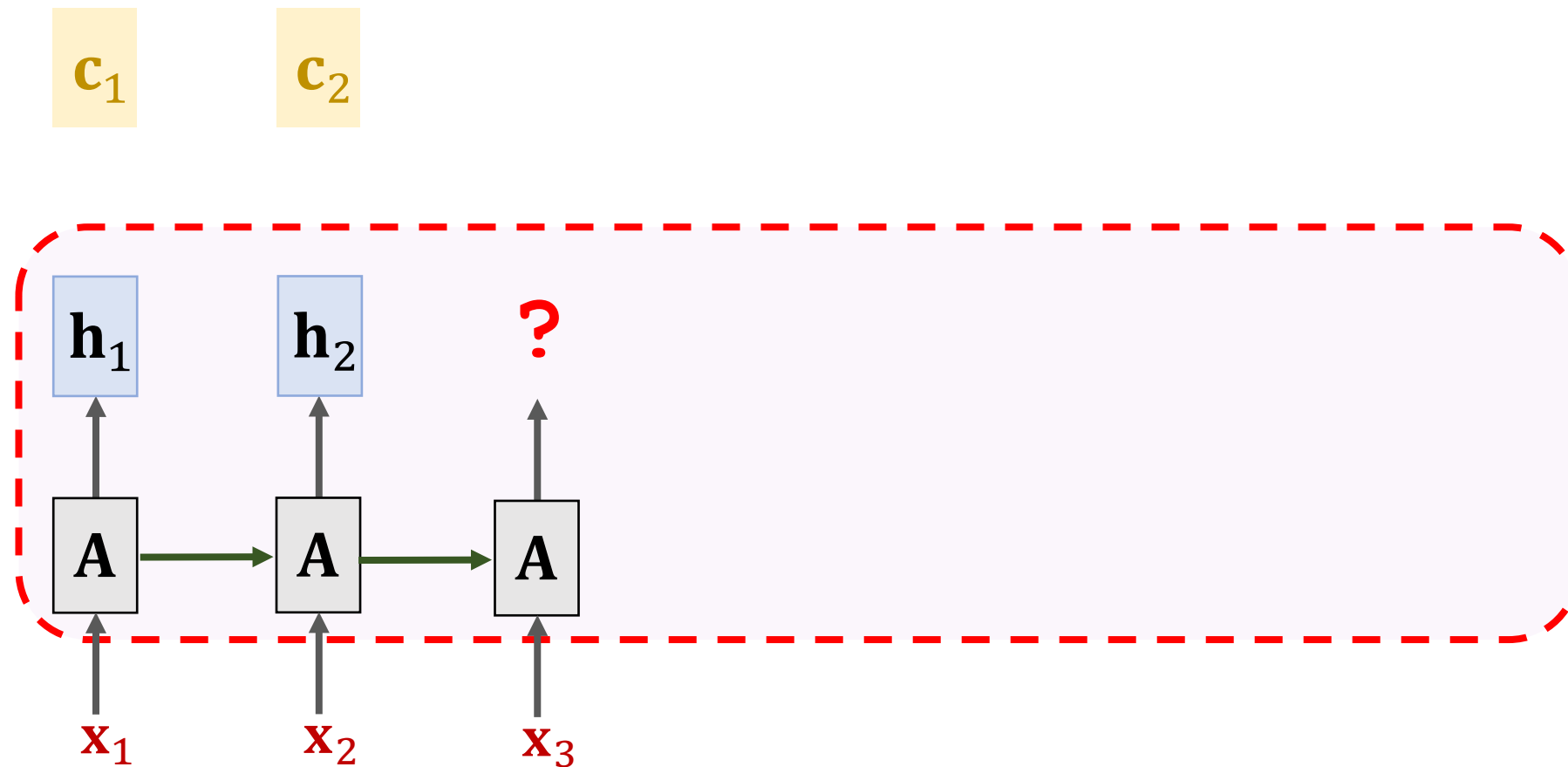
Context vector: $\mathbf{c}_2 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2.$

\mathbf{c}_1

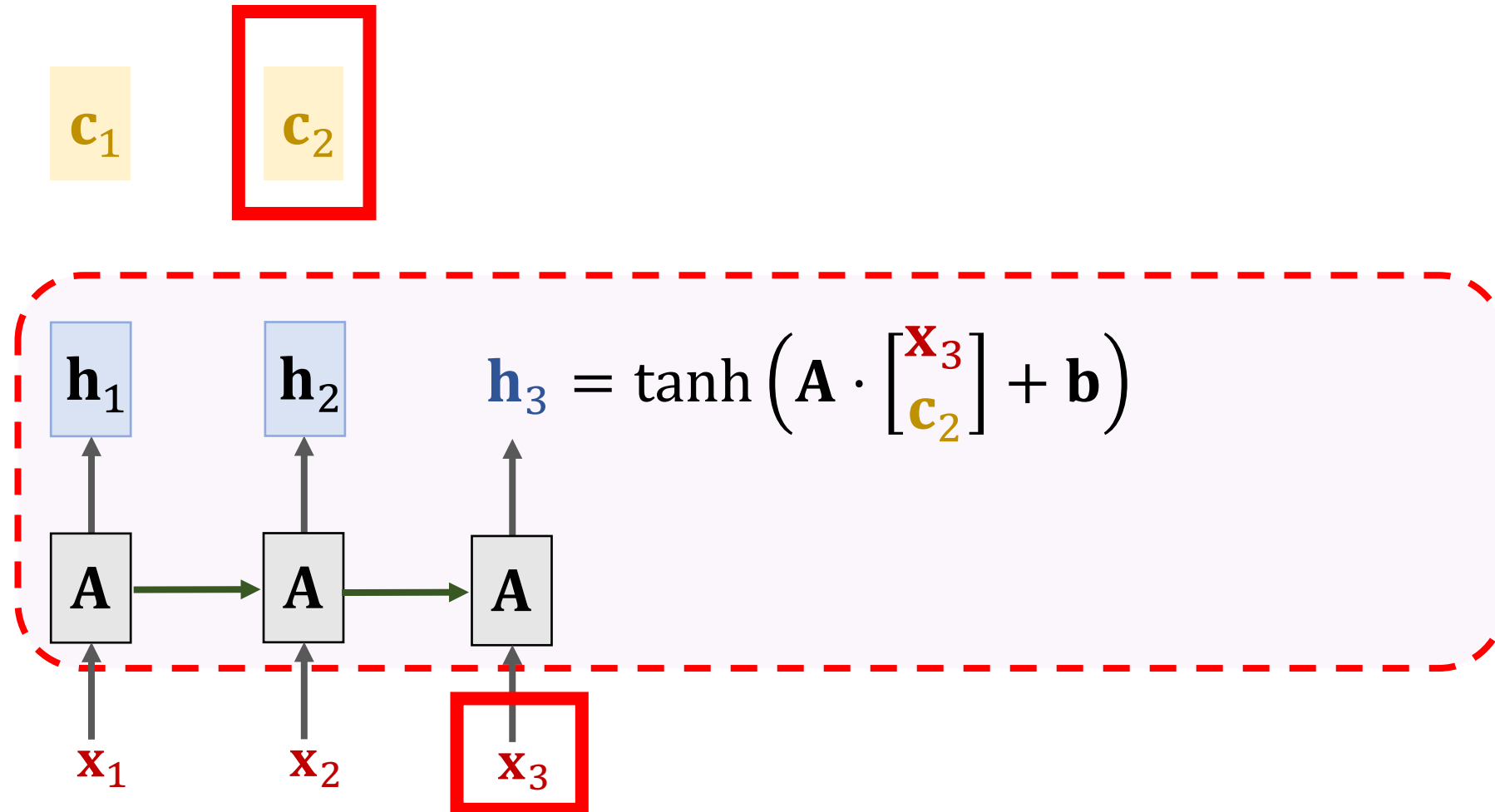
\mathbf{c}_2



SimpleRNN + Self-Attention



SimpleRNN + Self-Attention

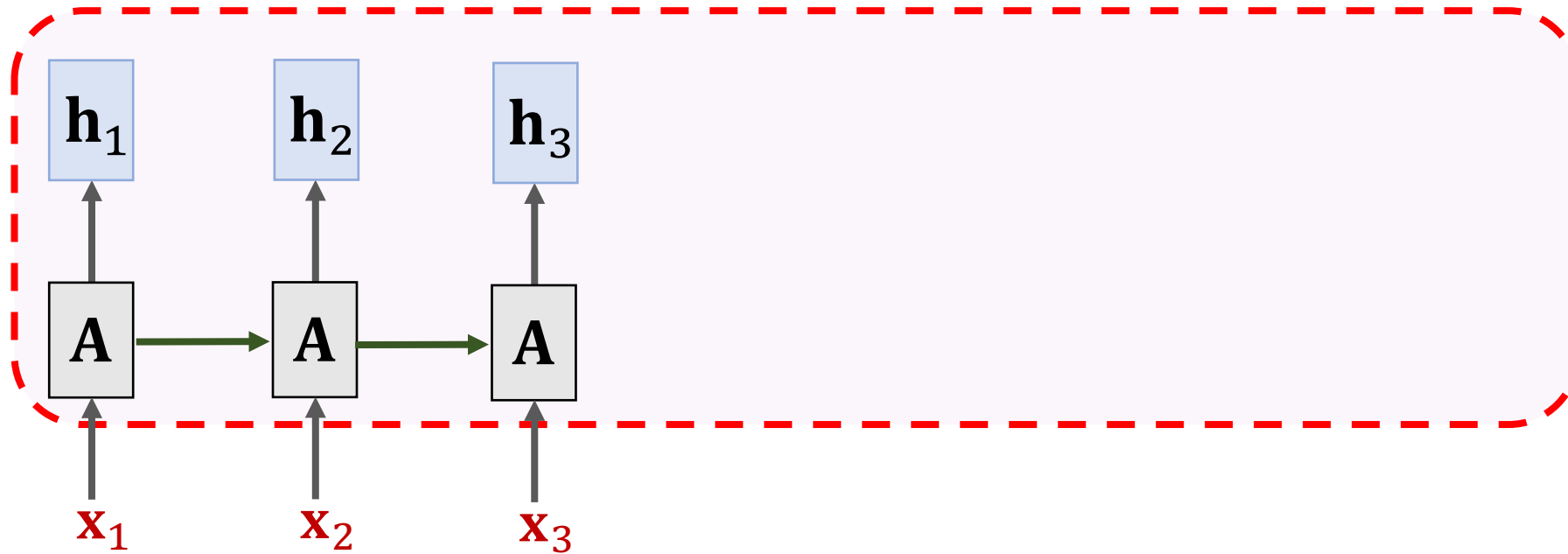


SimpleRNN + Self-Attention

\mathbf{c}_1

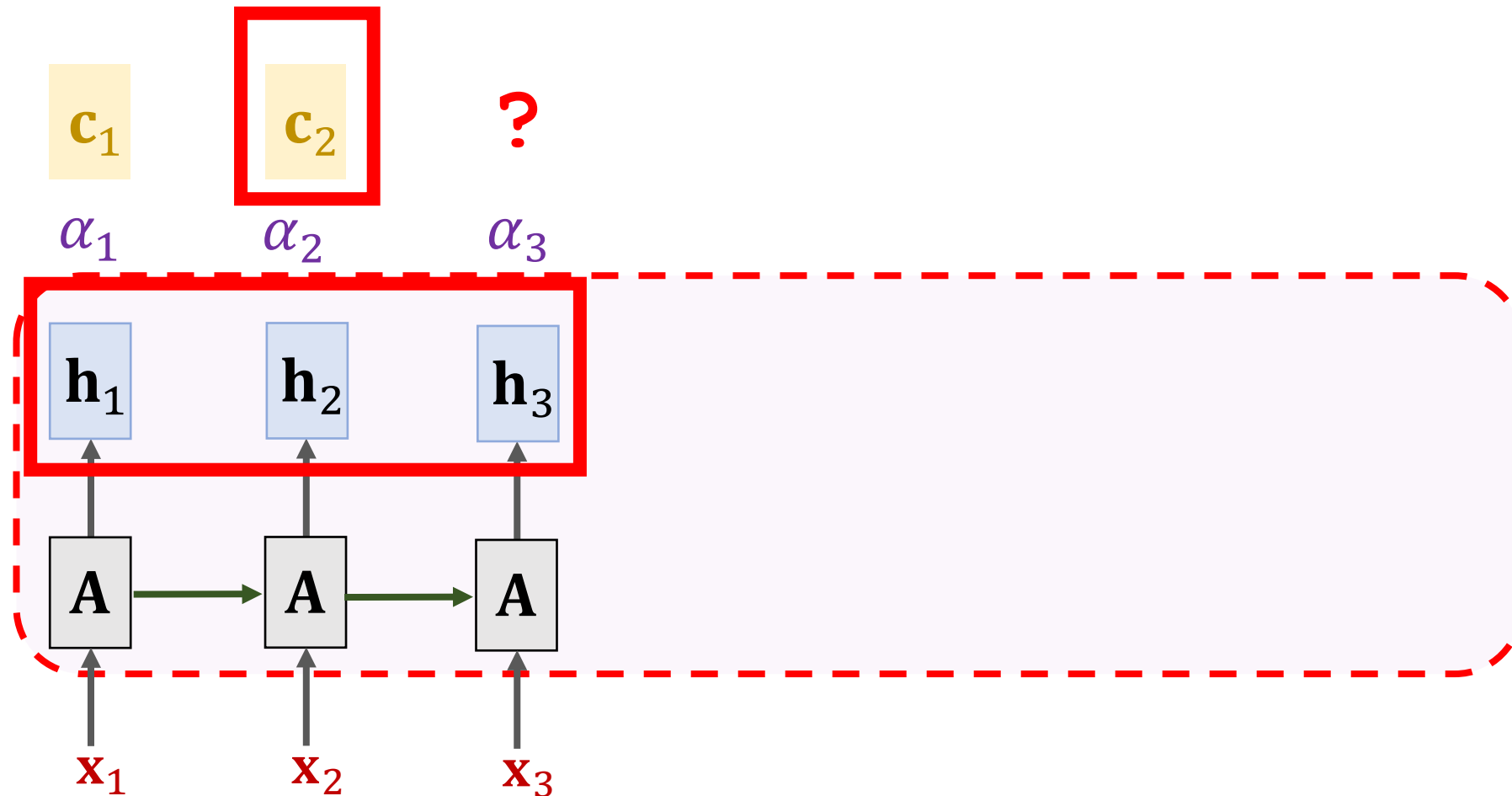
\mathbf{c}_2

?



SimpleRNN + Self-Attention

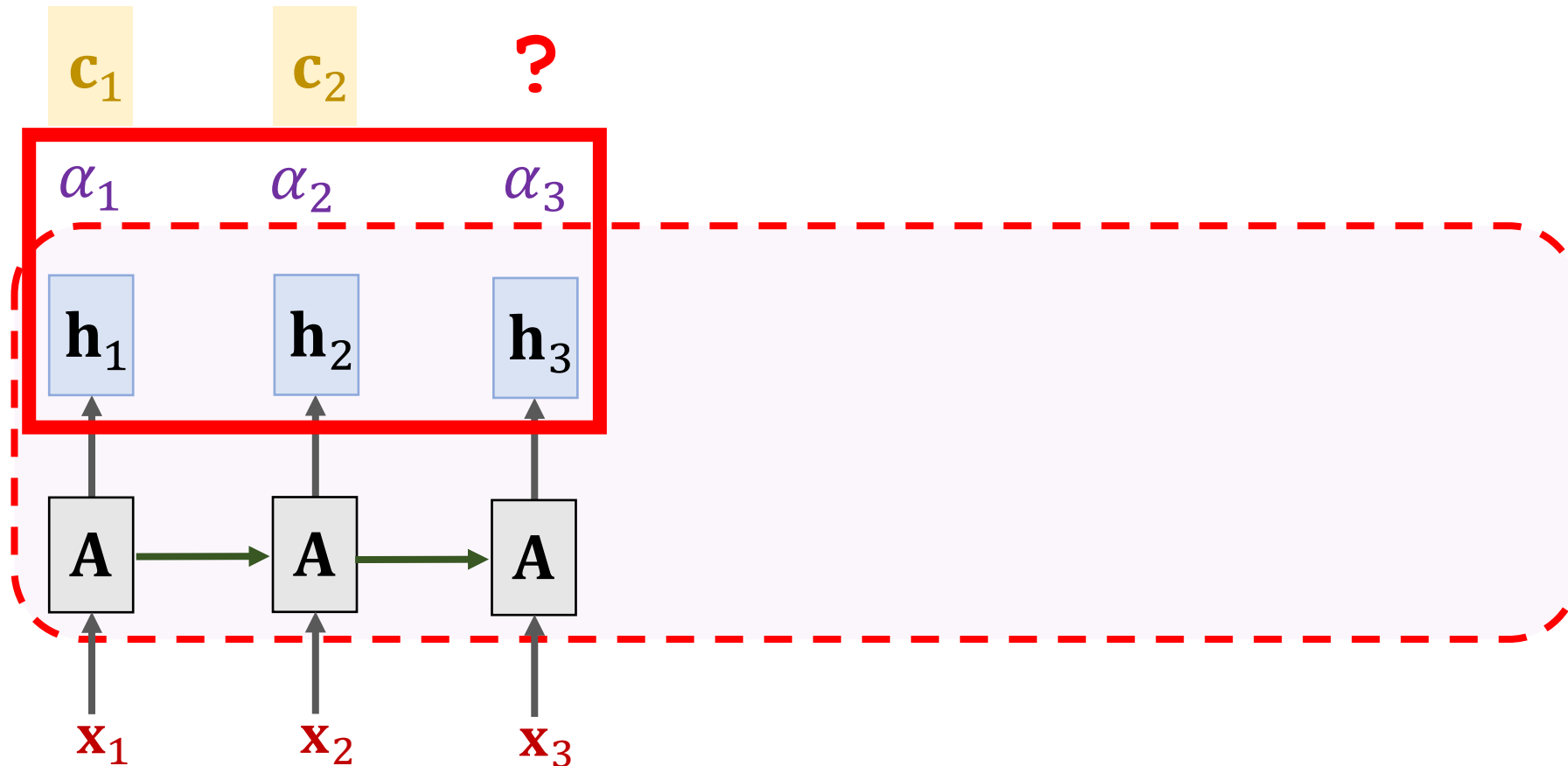
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_2)$



SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_2)$

Context vector: $\mathbf{c}_3 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2 + \alpha_3 \mathbf{h}_3.$

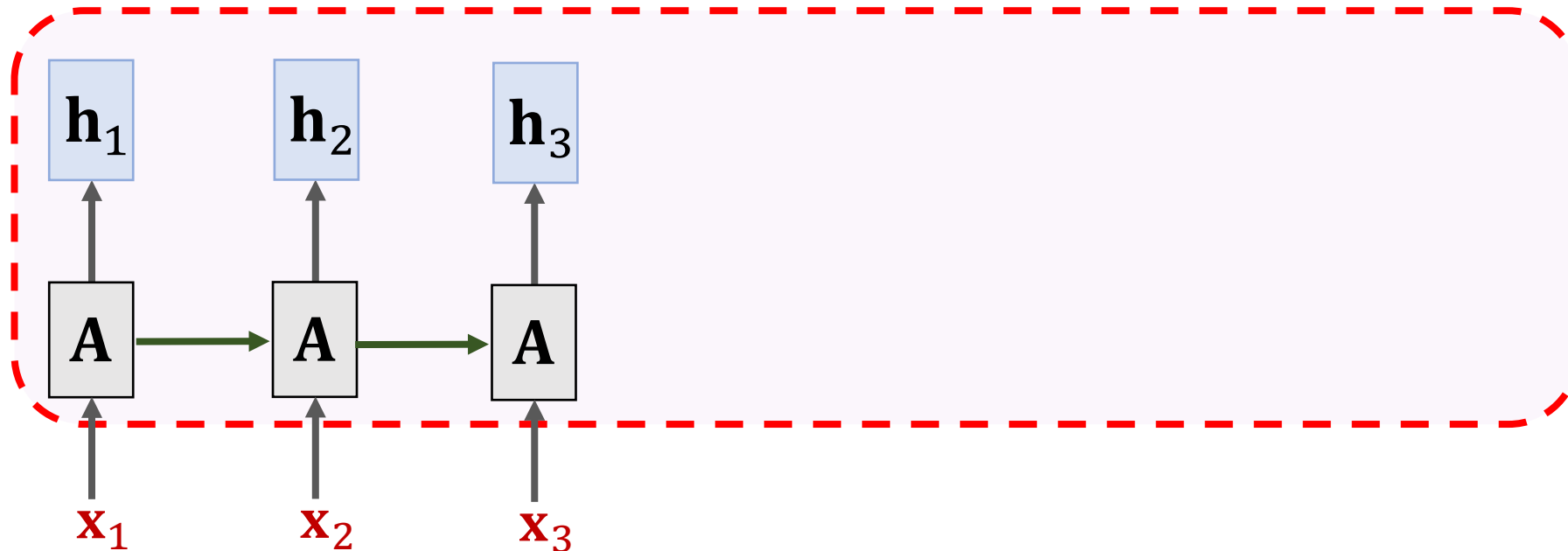


SimpleRNN + Self-Attention

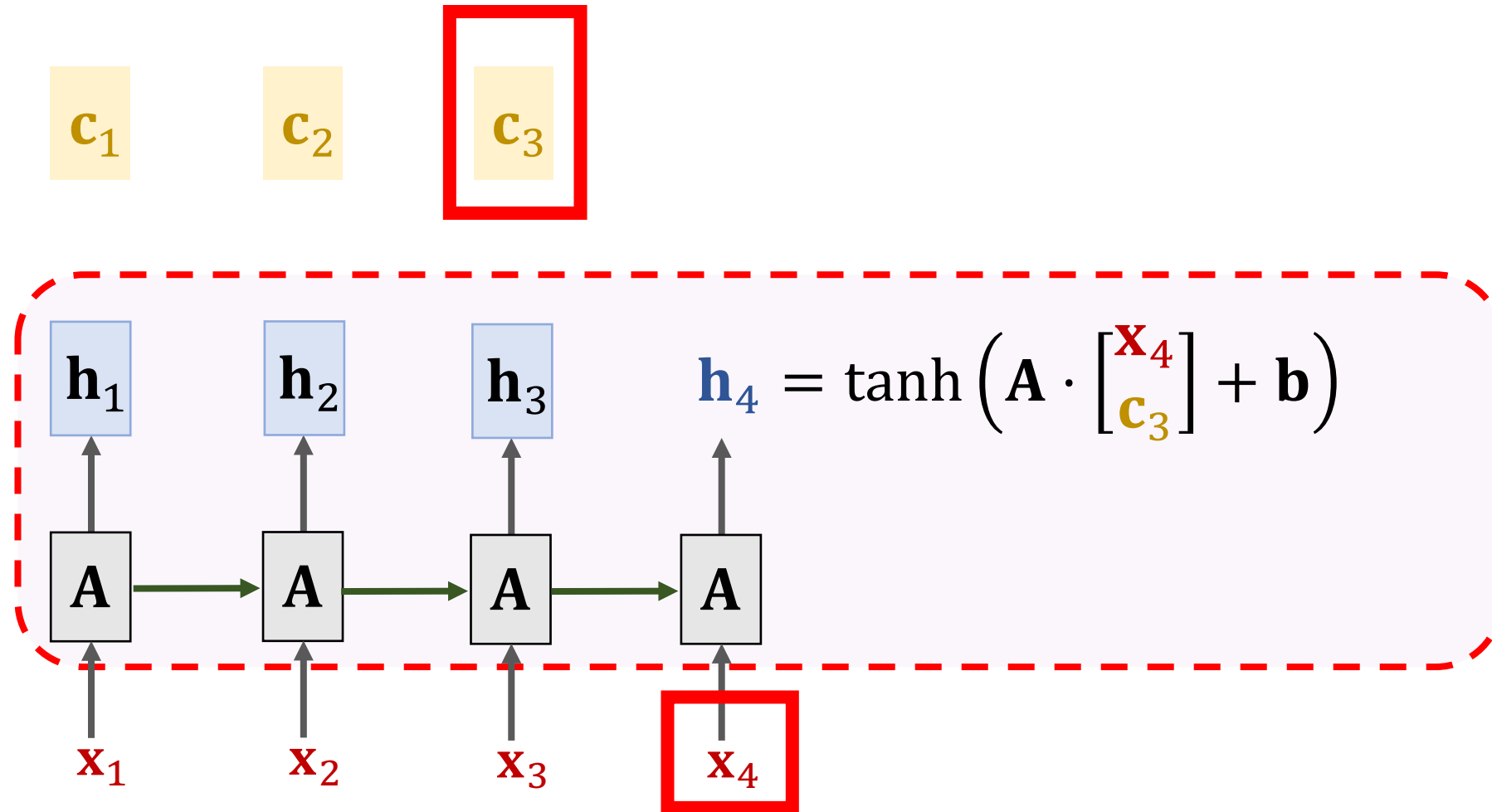
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_2)$

Context vector: $\mathbf{c}_3 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2 + \alpha_3 \mathbf{h}_3.$

\mathbf{c}_1 \mathbf{c}_2 \mathbf{c}_3



SimpleRNN + Self-Attention



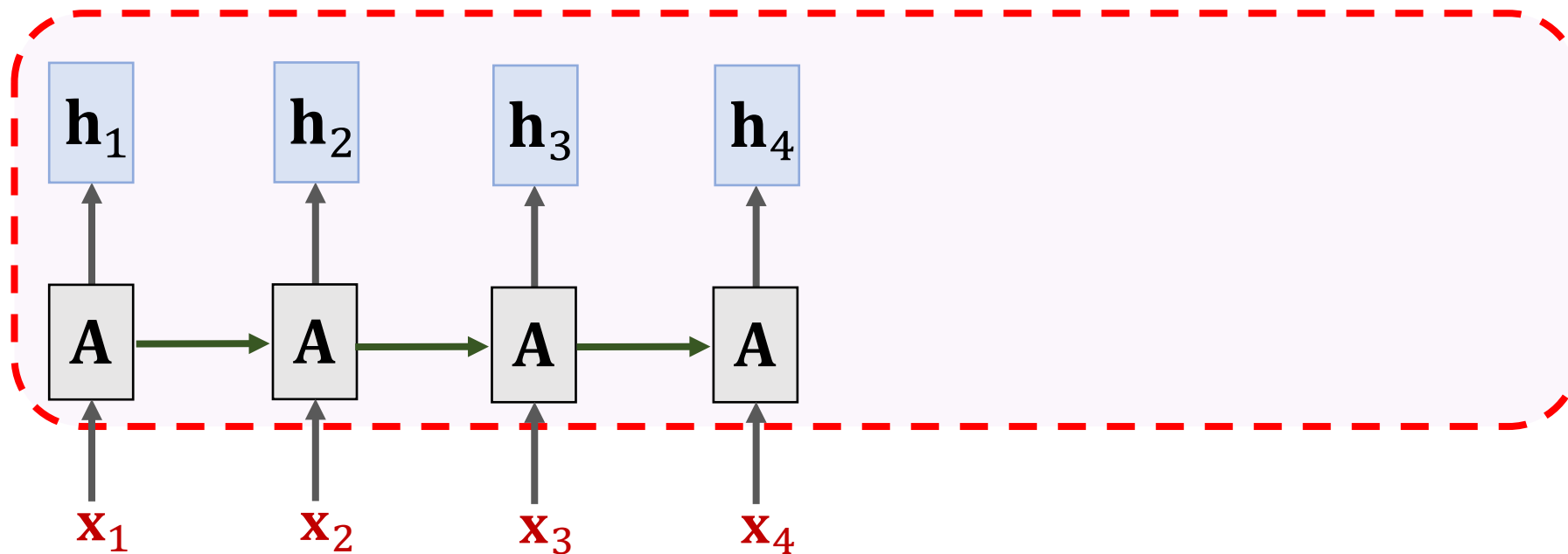
SimpleRNN + Self-Attention

\mathbf{c}_1

\mathbf{c}_2

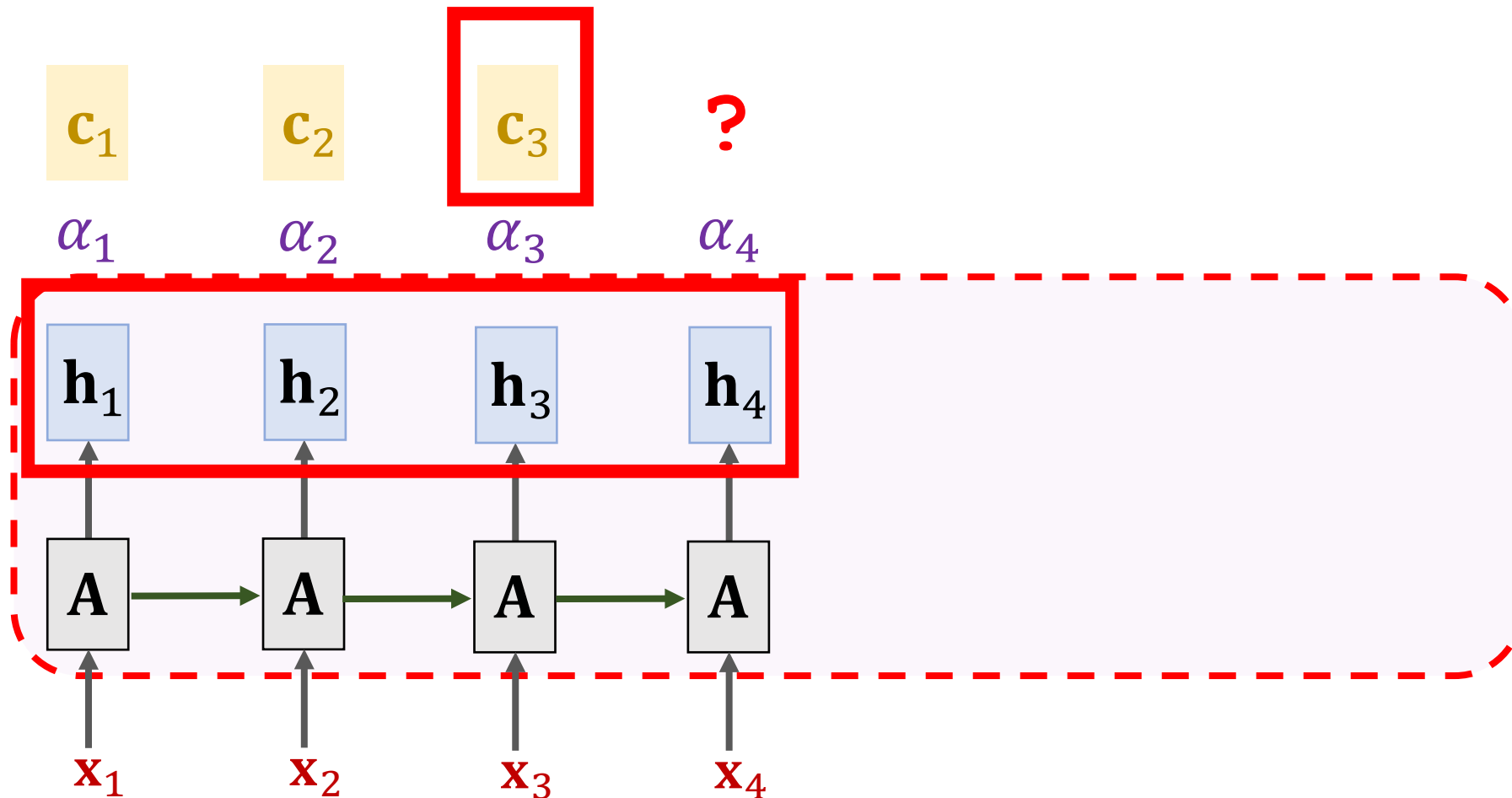
\mathbf{c}_3

?



SimpleRNN + Self-Attention

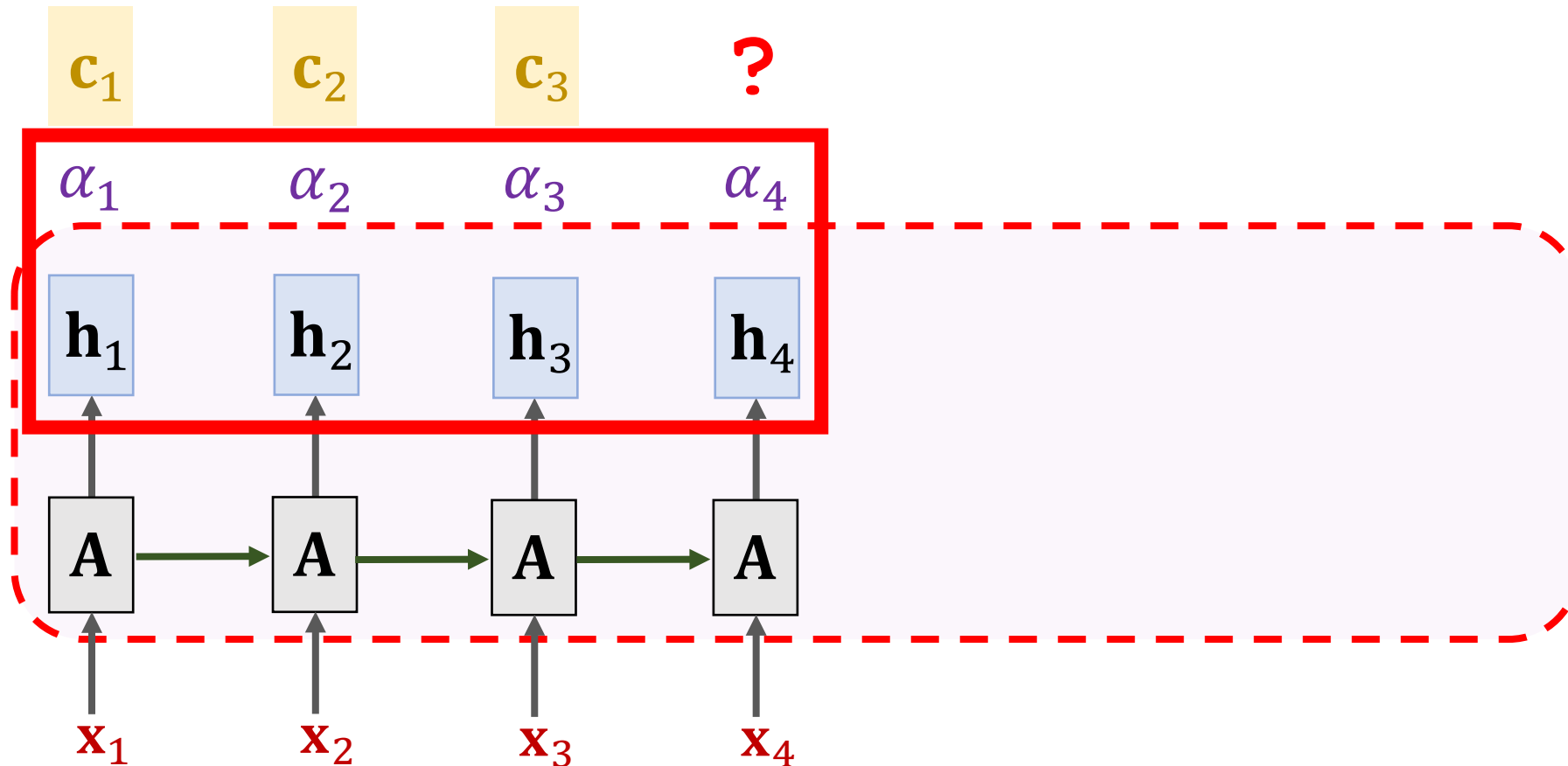
Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_3)$



SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_3)$

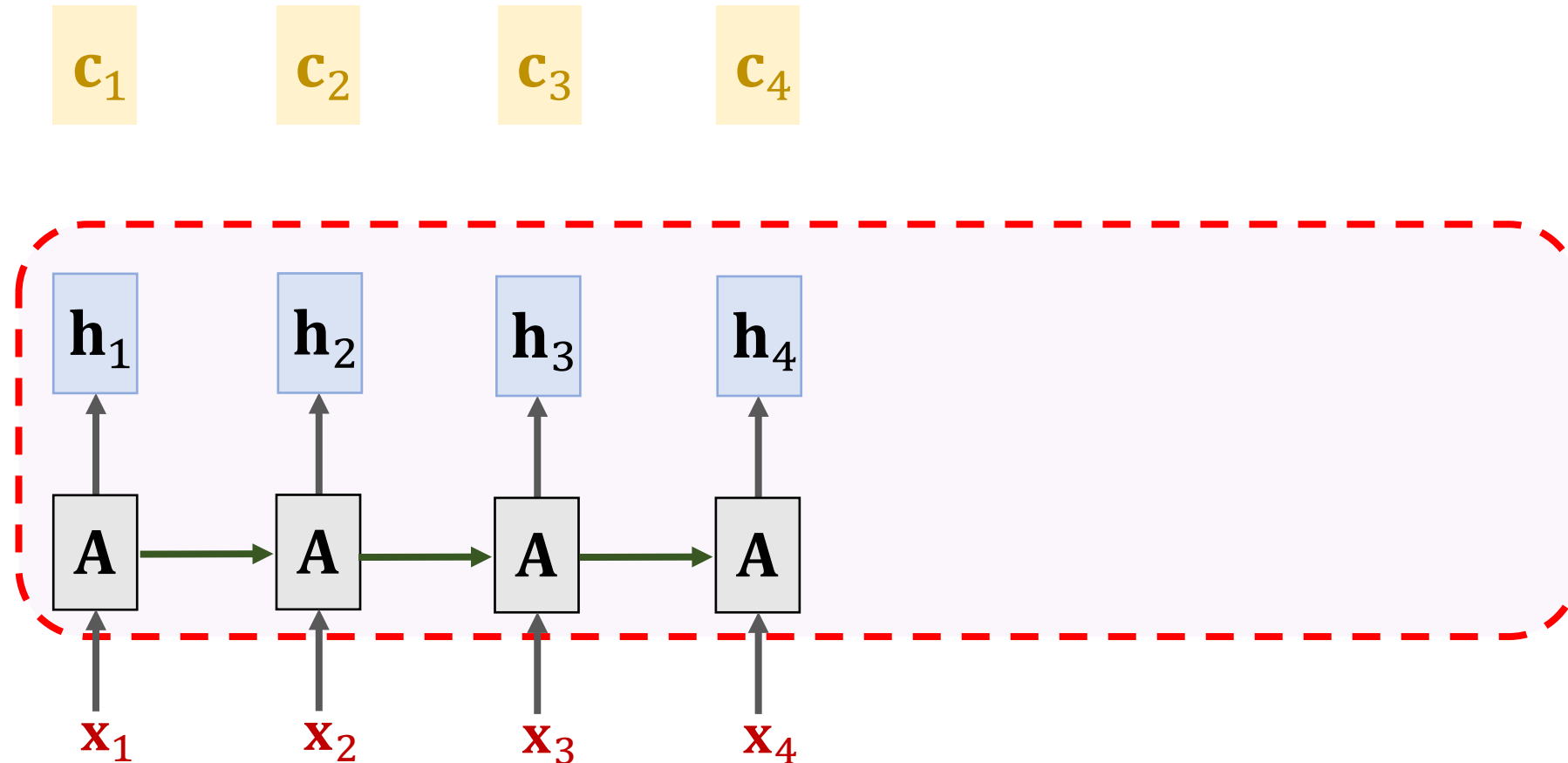
Context vector: $\mathbf{c}_4 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2 + \alpha_3 \mathbf{h}_3 + \alpha_4 \mathbf{h}_4.$



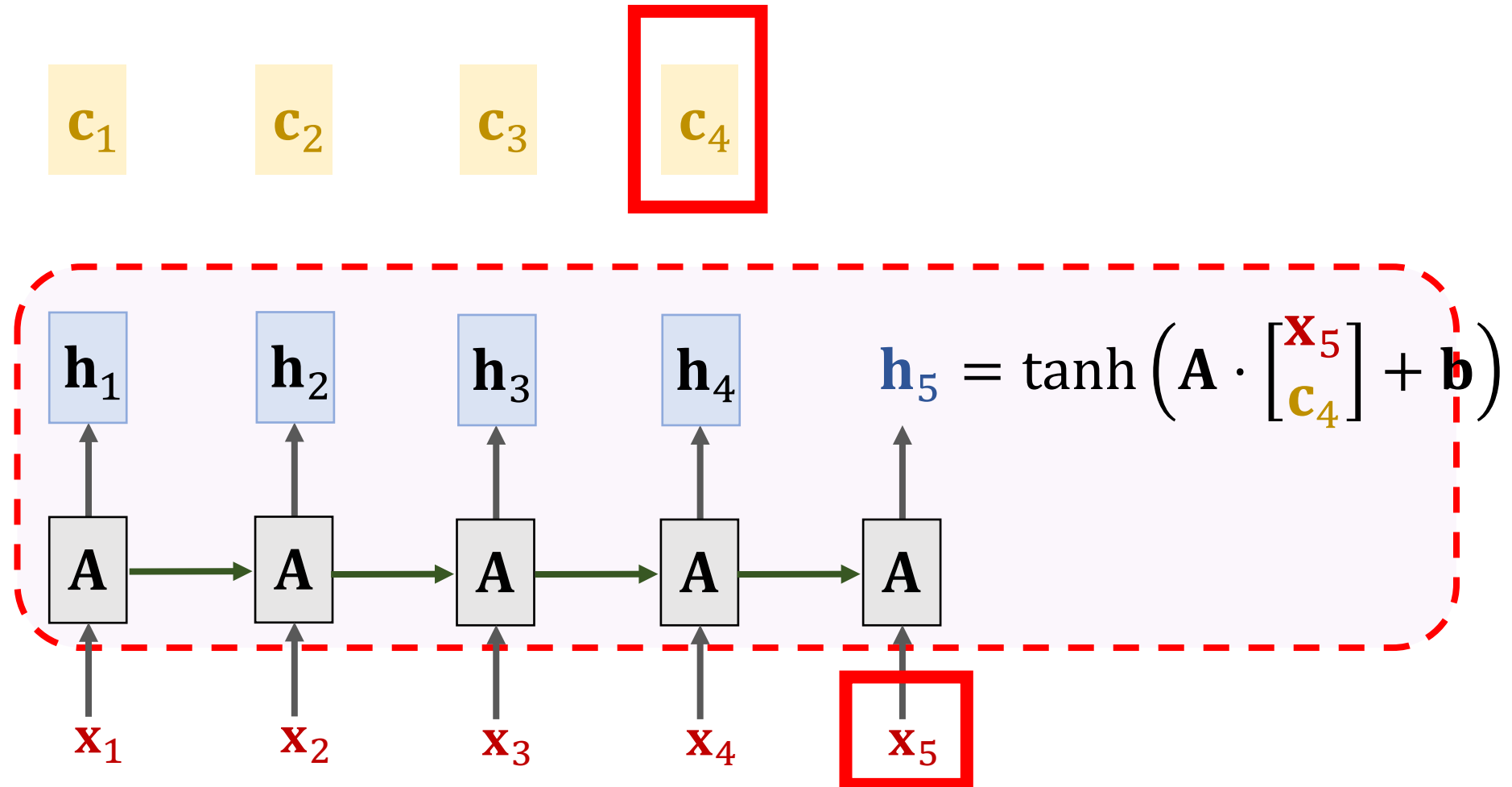
SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_3)$

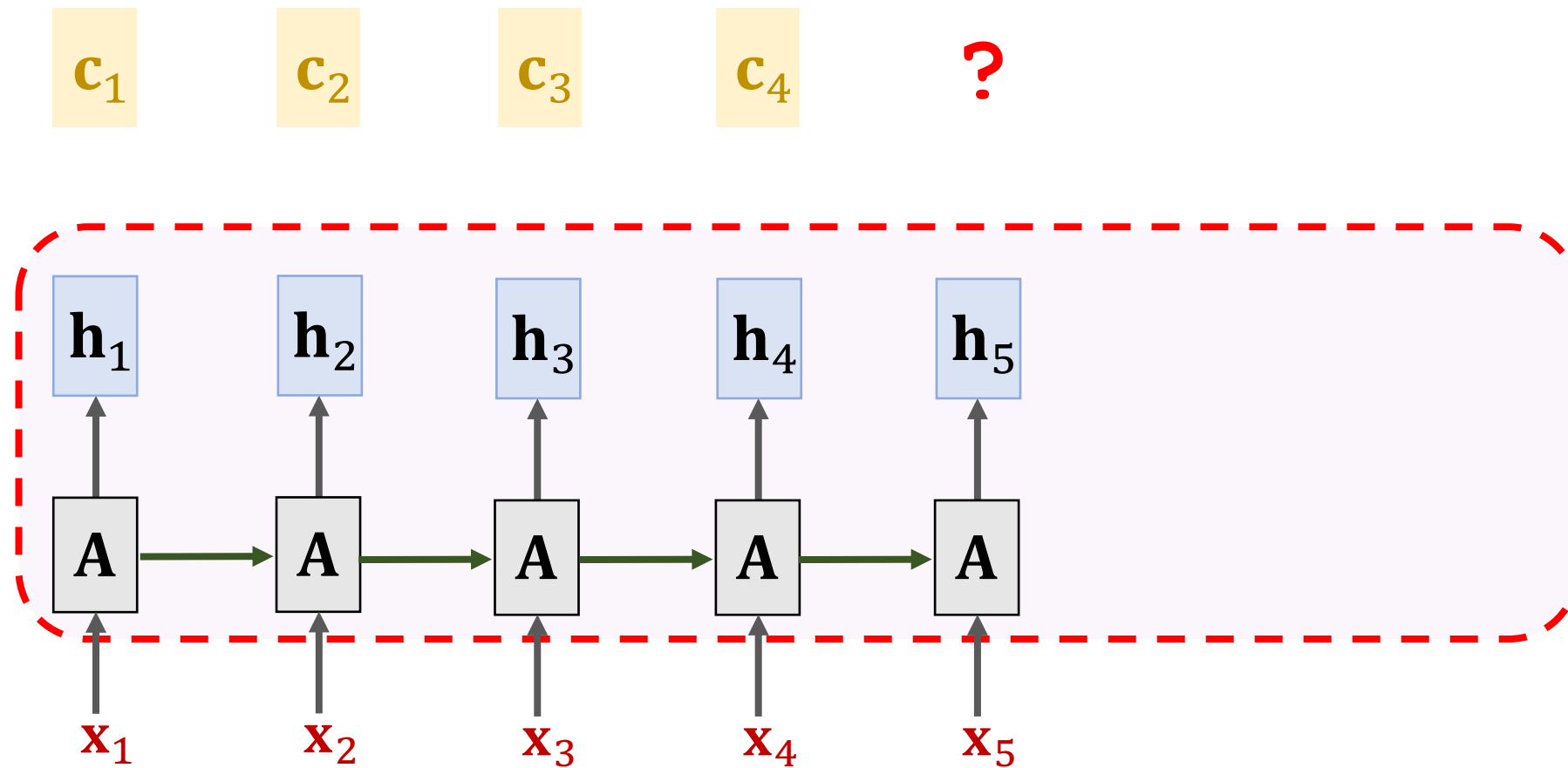
Context vector: $\mathbf{c}_4 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2 + \alpha_3 \mathbf{h}_3 + \alpha_4 \mathbf{h}_4.$



SimpleRNN + Self-Attention



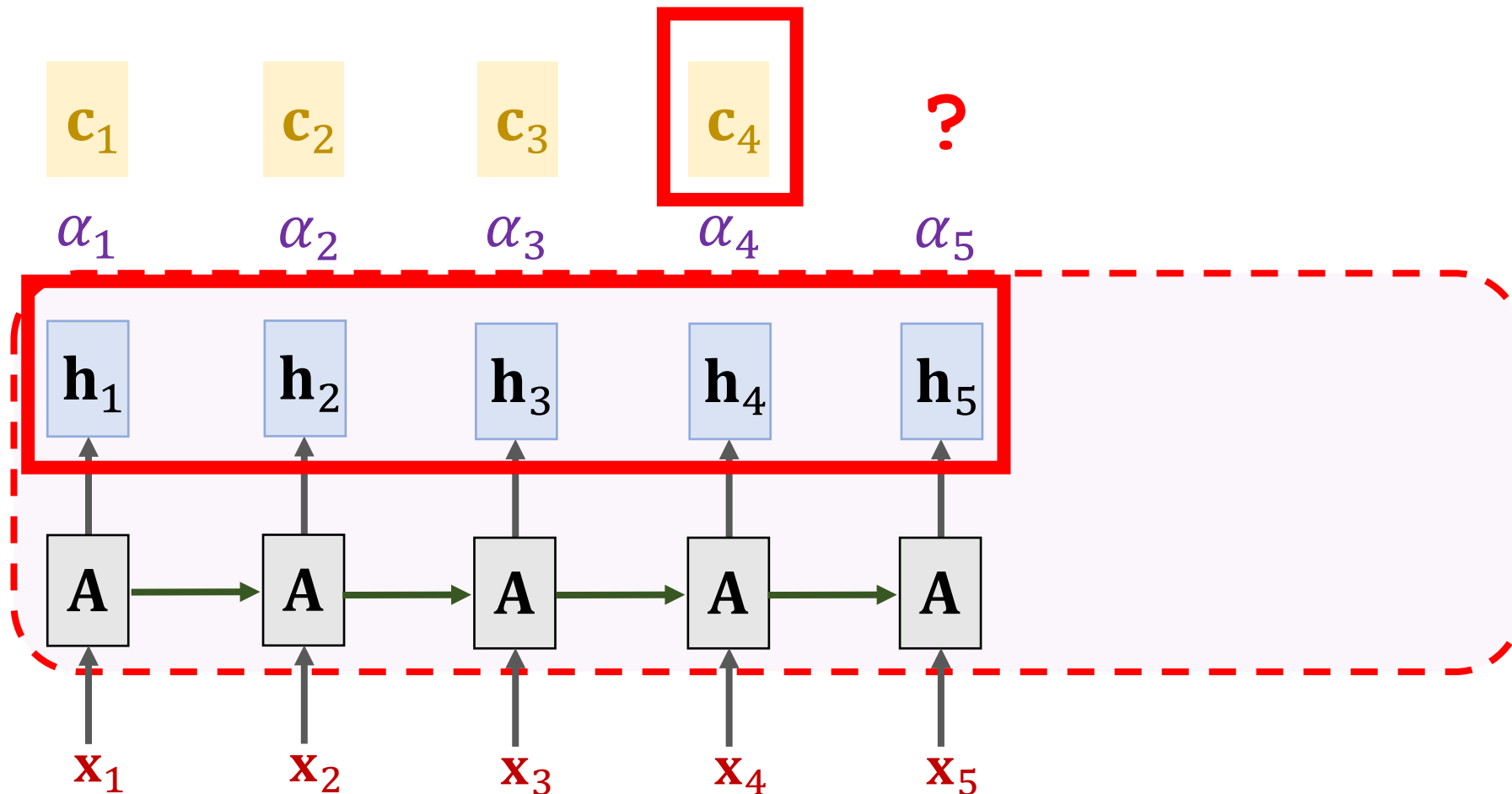
SimpleRNN + Self-Attention



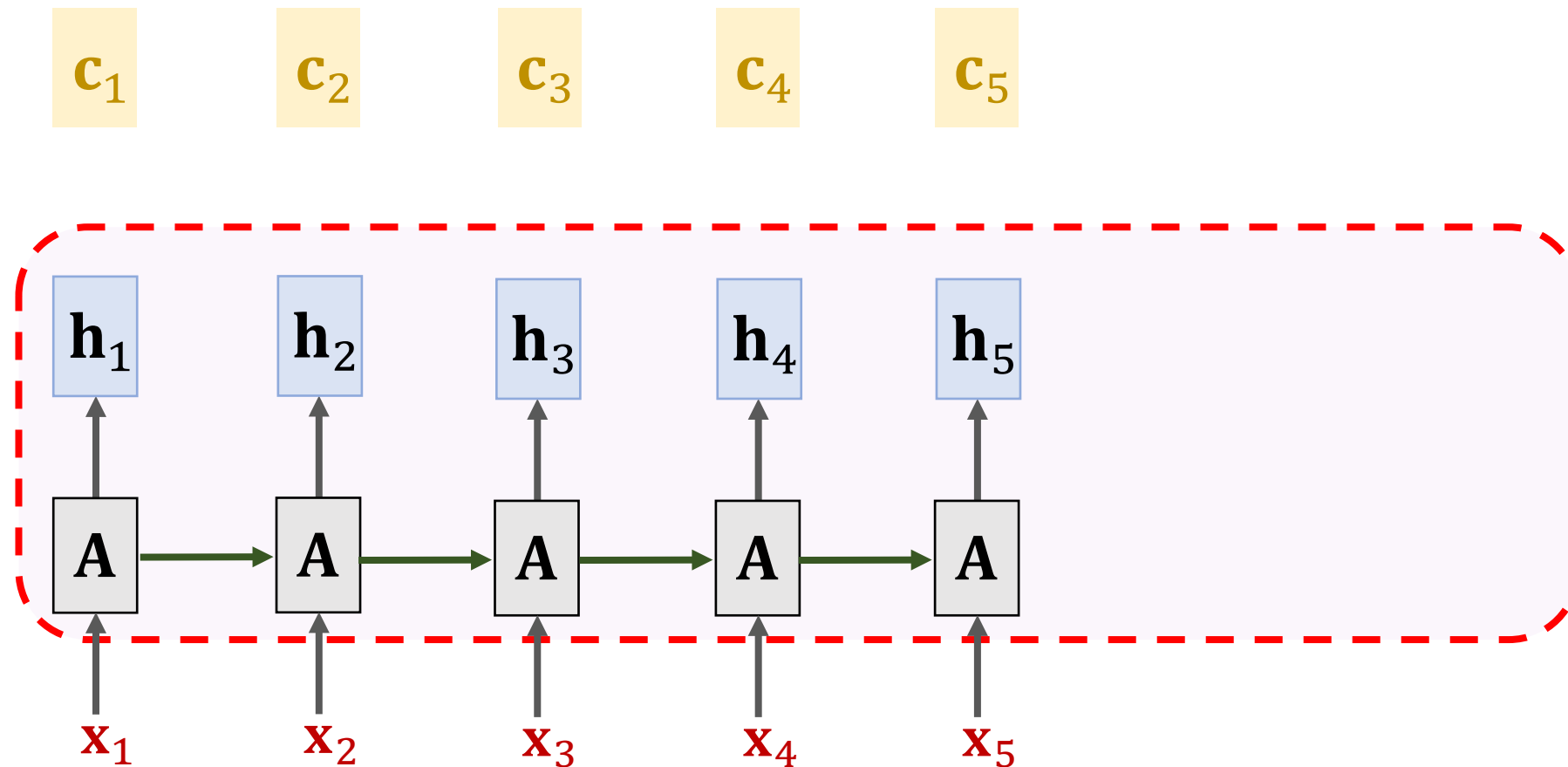
SimpleRNN + Self-Attention

Weights: $\alpha_i = \text{similarity}(\mathbf{h}_i, \mathbf{c}_3)$

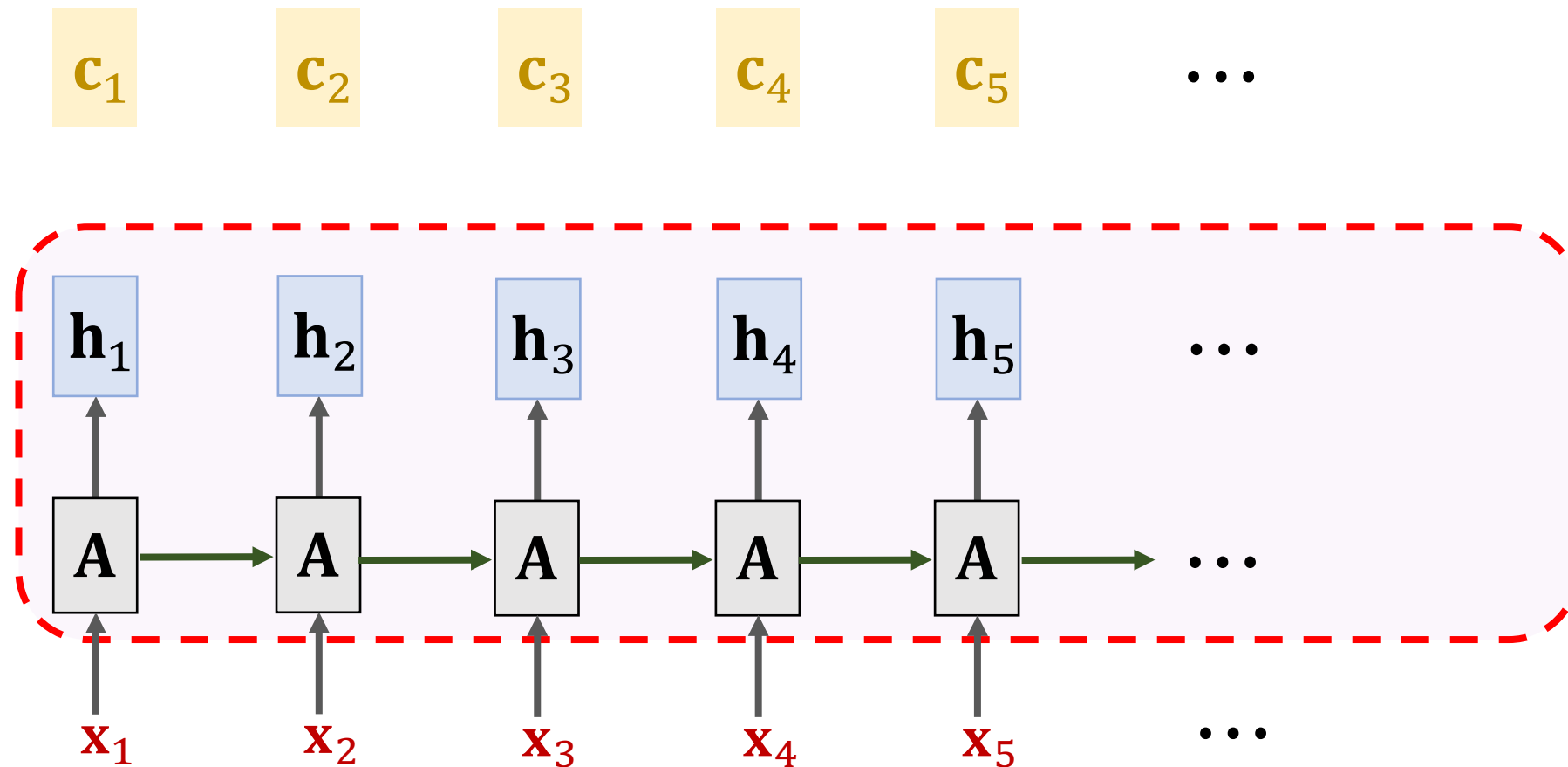
Context vector: $\mathbf{c}_5 = \alpha_1 \mathbf{h}_1 + \alpha_2 \mathbf{h}_2 + \cdots + \alpha_5 \mathbf{h}_5.$



SimpleRNN + Self-Attention



SimpleRNN + Self-Attention



Summary

- With self-attention, RNN is less likely to forget.

Summary

- With self-attention, RNN is less likely to forget.
- Pay attention to the context relevant to the new input.

The

The FBI

The FBI is

The FBI is chasing

The FBI is chasing a

The FBI is chasing a criminal

The FBI is chasing a criminal on

The FBI is chasing a criminal on the

The FBI is chasing a criminal on the run

The FBI is chasing a criminal on the run .

Figure is from the paper “ Long Short-Term Memory-Networks for Machine Reading.”