CS5242 : Neural Networks and Deep Learning

Lecture 11: Recurrent Neural Networks Applications

Semester 1 2021/22

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Outline

- Speech recognition
  - Introduction
  - Spectrogram
  - Inference
- Machine Translation
  - Introduction
  - Architecture
  - Inference
  - Training

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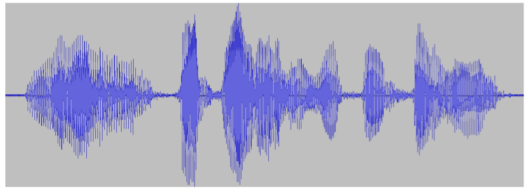
Speech recognition

- Speech-to-text is a fundamental task :
  - Virtual assistants : Apple Siri, Amazon Alexa, Microsoft Cortana, Google Assistant require to change the speech signal into a sequence of words.
  - Beyond keyboard : Speech recognition in-place of keyboard (when error is less than 1%).
  - Current performances: 5.1% error by Microsoft Research, as good as human transcript.



Input :
Speech signal

Neural Net

"call a taxi"

Output:
Sequence of words

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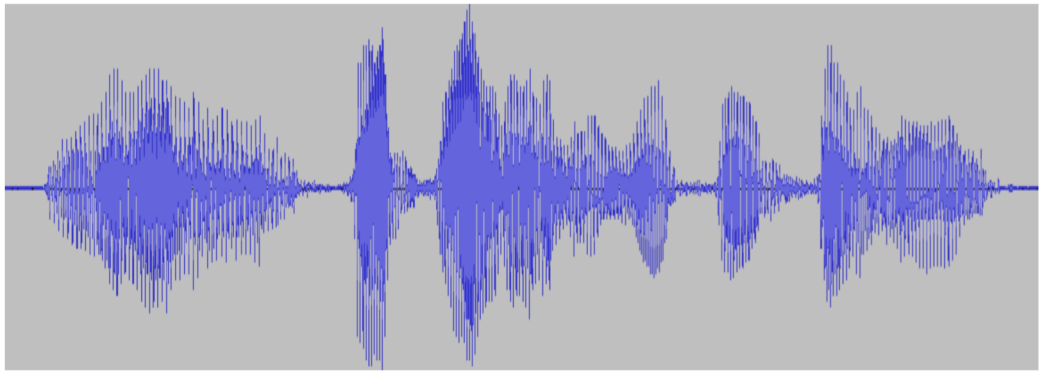
Spectrogram

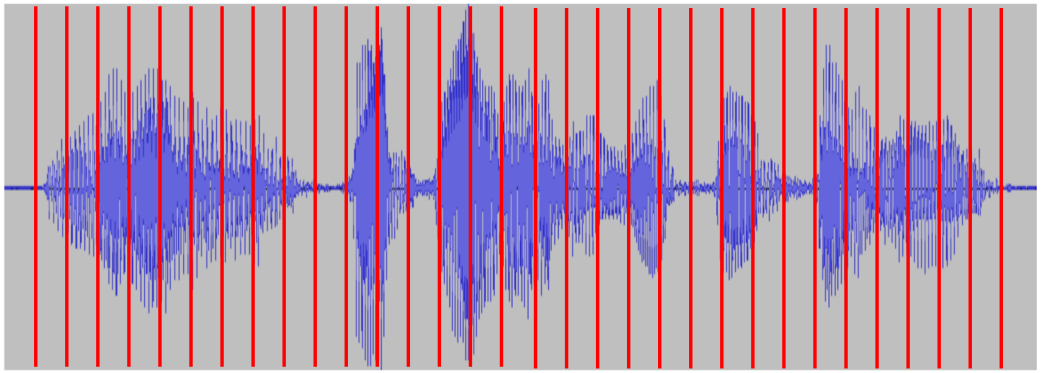
- We pre-process the raw audio signal to extract temporal and frequencial information.



Raw audio signal

Spectrogram

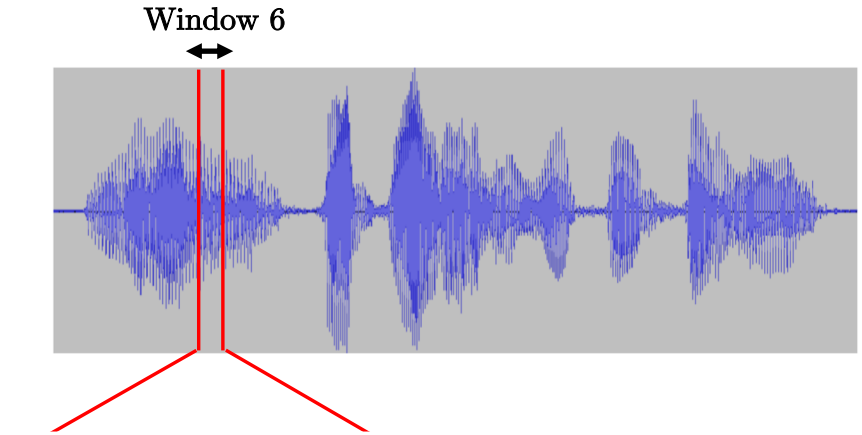
- First, we cut the raw audio signal into small windows of 20 ms :

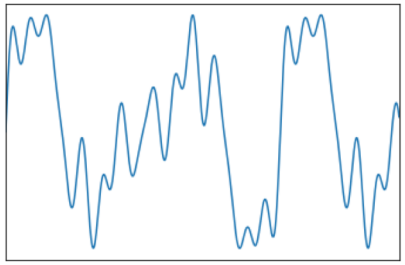


Window 6
20 ms

Spectrogram

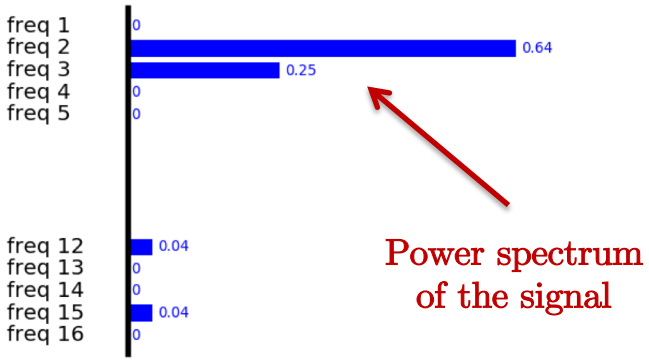
- We compute the power spectrum of the signal (Fourier transform) for each window :





The audio signal is made of multiple frequencies.

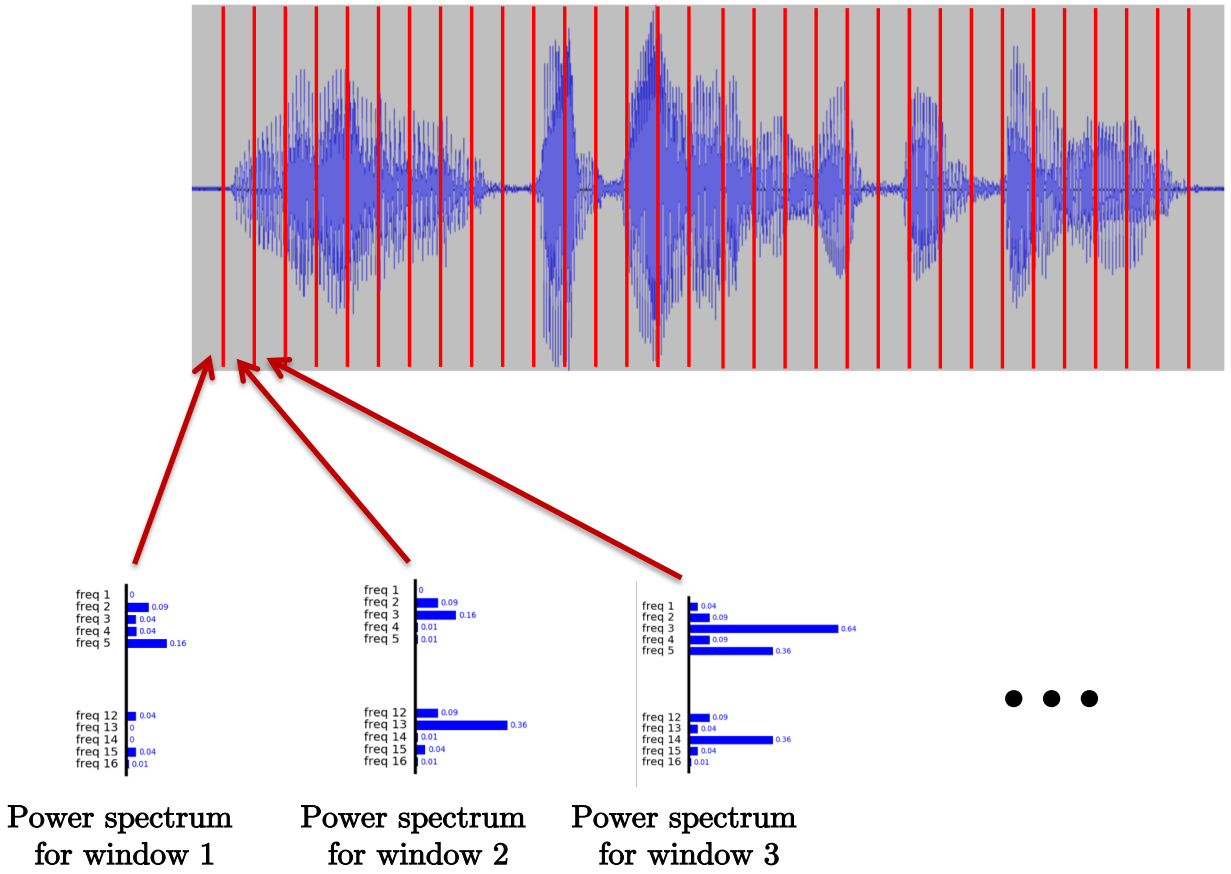
Fourier transform



Power spectrum of the signal

Spectrogram

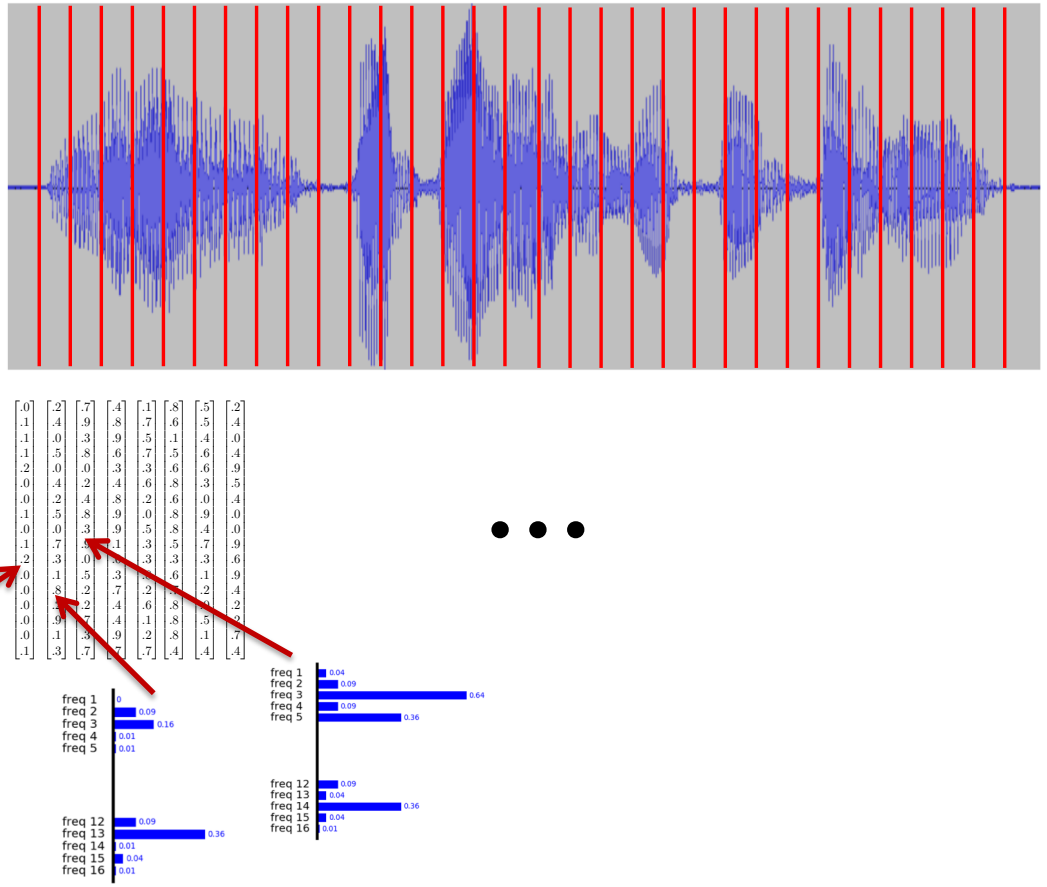
- We compute the power spectrum for all 20ms windows :



Power spectrum for window 1 | Power spectrum for window 2 | Power spectrum for window 3

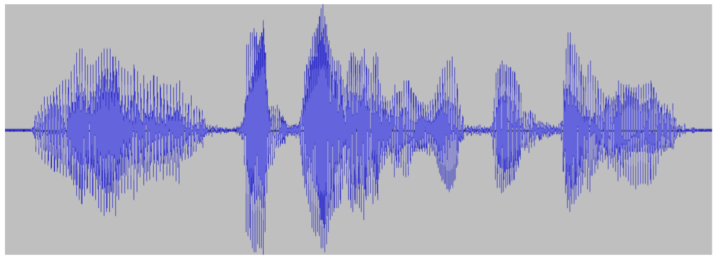
Spectrogram

- We compute the power spectrum of all 20ms windows :



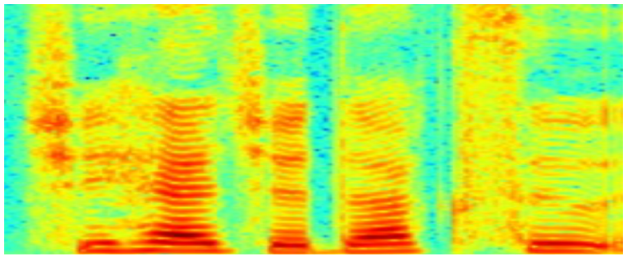
Spectrogram

- The raw audio signal has been converted into a sequence of vectors (size is between 100-200).
- This sequence of vectors is called the spectrogram.
- It can be computed very quickly with FFT.



Raw audio signal

$\Rightarrow$



Spectogram

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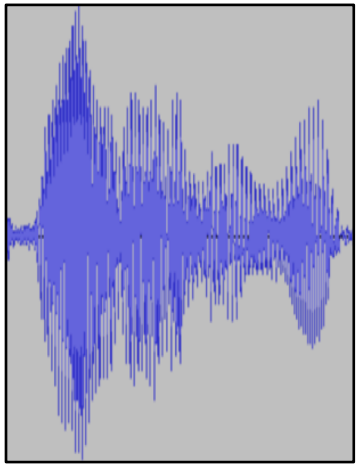
Inference

- Inference process :
  - Feed the sequence of vectors (spectogram) to a trained RNN :



$$\begin{bmatrix}.0\\.1\\.1\\.1\\.2\\.0\\.0\\.1\\.0\\.1\\.2\\.0\\.0\\.0\\.0\\.0\\.1\end{bmatrix}\begin{bmatrix}.2\\.4\\.0\\.5\\.0\\.4\\.2\\.5\\.0\\.7\\.3\\.1\\.8\\.2\\.9\\.1\\.3\end{bmatrix}\begin{bmatrix}.7\\.9\\.3\\.8\\.0\\.2\\.4\\.8\\.3\\.9\\.0\\.5\\.2\\.2\\.7\\.3\\.7\end{bmatrix}\begin{bmatrix}.4\\.8\\.9\\.6\\.3\\.4\\.8\\.9\\.9\\.1\\.0\\.3\\.7\\.4\\.4\\.9\\.7\end{bmatrix}\begin{bmatrix}.1\\.7\\.5\\.7\\.3\\.6\\.2\\.0\\.5\\.3\\.3\\.8\\.2\\.6\\.1\\.2\\.7\end{bmatrix}\begin{bmatrix}.8\\.6\\.1\\.5\\.6\\.8\\.6\\.8\\.8\\.5\\.3\\.6\\.7\\.8\\.8\\.8\\.4\end{bmatrix}\begin{bmatrix}.5\\.5\\.4\\.6\\.6\\.3\\.0\\.9\\.4\\.7\\.3\\.1\\.2\\.0\\.5\\.1\\.4\end{bmatrix}\begin{bmatrix}.2\\.4\\.0\\.4\\.9\\.5\\.4\\.0\\.0\\.9\\.6\\.9\\.4\\.2\\.2\\.7\\.4\end{bmatrix}$$

Neural Net

"Hello"

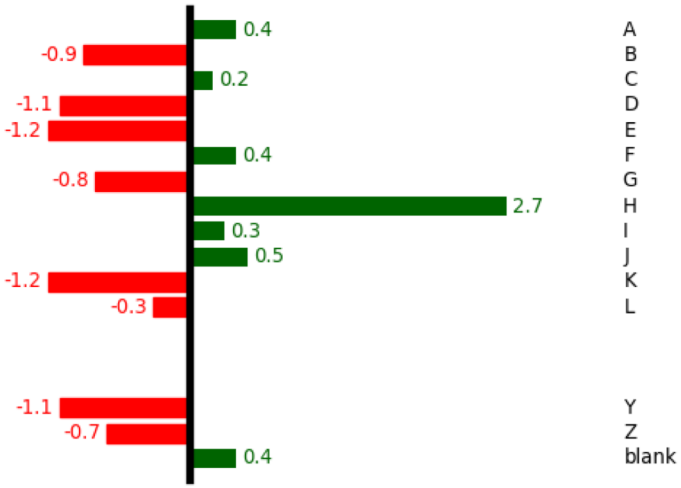
Input :
Audio signal

Spectogram

Output :
Sequence of words

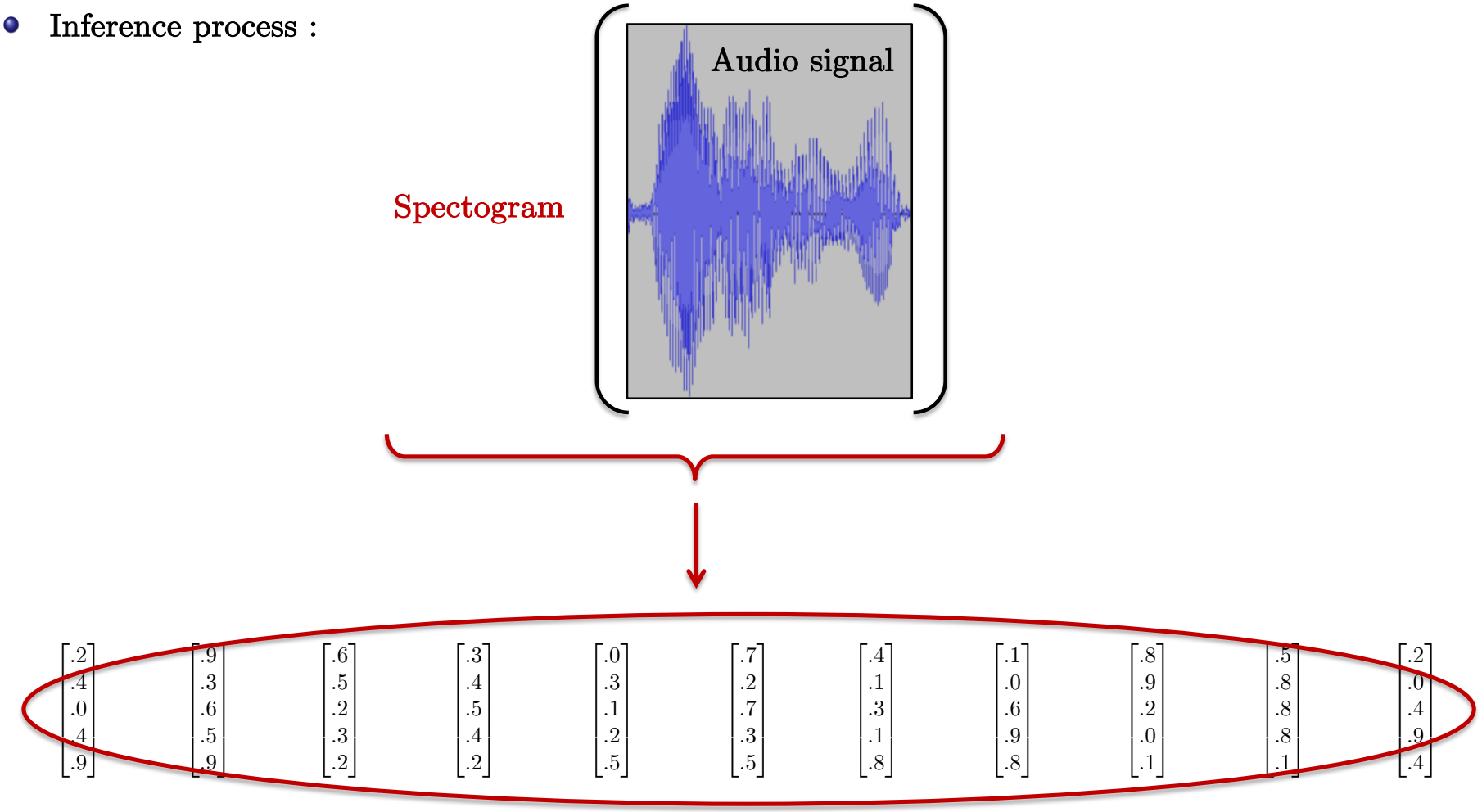
Inference

- Dictionary/vocabulary is defined as follows :
  - 27 classes :
    - The 26 letters of the alphabet
    - Blank symbol
    - Space Symbol



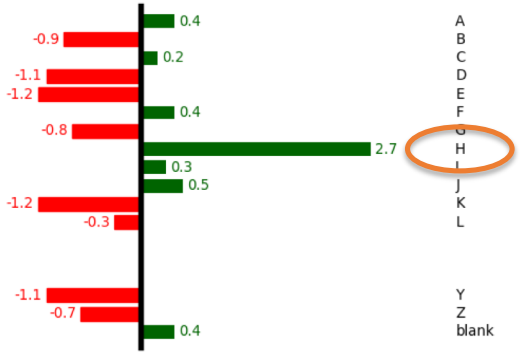
Inference

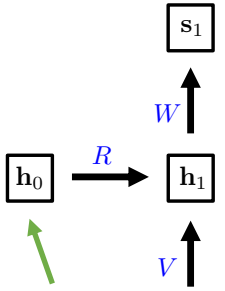
- Inference process :



Inference

- Inference process : Softmax the letter corresponding to the input spectrogram vector.



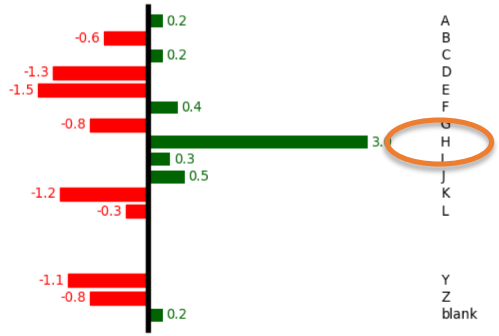


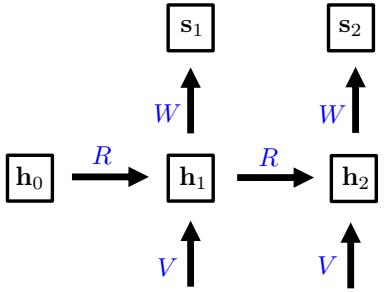
Hidden states initialized to zero vectors.

$$\begin{bmatrix}.2\\.4\\.0\\.4\\.9\end{bmatrix} \begin{bmatrix}.9\\.3\\.6\\.5\\.9\end{bmatrix} \begin{bmatrix}.6\\.5\\.2\\.3\\.2\end{bmatrix} \begin{bmatrix}.3\\.4\\.5\\.4\\.2\end{bmatrix} \begin{bmatrix}.0\\.3\\.1\\.2\\.5\end{bmatrix} \begin{bmatrix}.7\\.2\\.7\\.3\\.5\end{bmatrix} \begin{bmatrix}.4\\.1\\.3\\.1\\.8\end{bmatrix} \begin{bmatrix}.1\\.0\\.6\\.9\\.8\end{bmatrix} \begin{bmatrix}.8\\.9\\.2\\.0\\.1\end{bmatrix} \begin{bmatrix}.5\\.8\\.8\\.8\\.1\end{bmatrix} \begin{bmatrix}.2\\.0\\.4\\.9\\.4\end{bmatrix}$$

Inference

- Inference process : Softmax the letter corresponding to the input spectrogram vector.

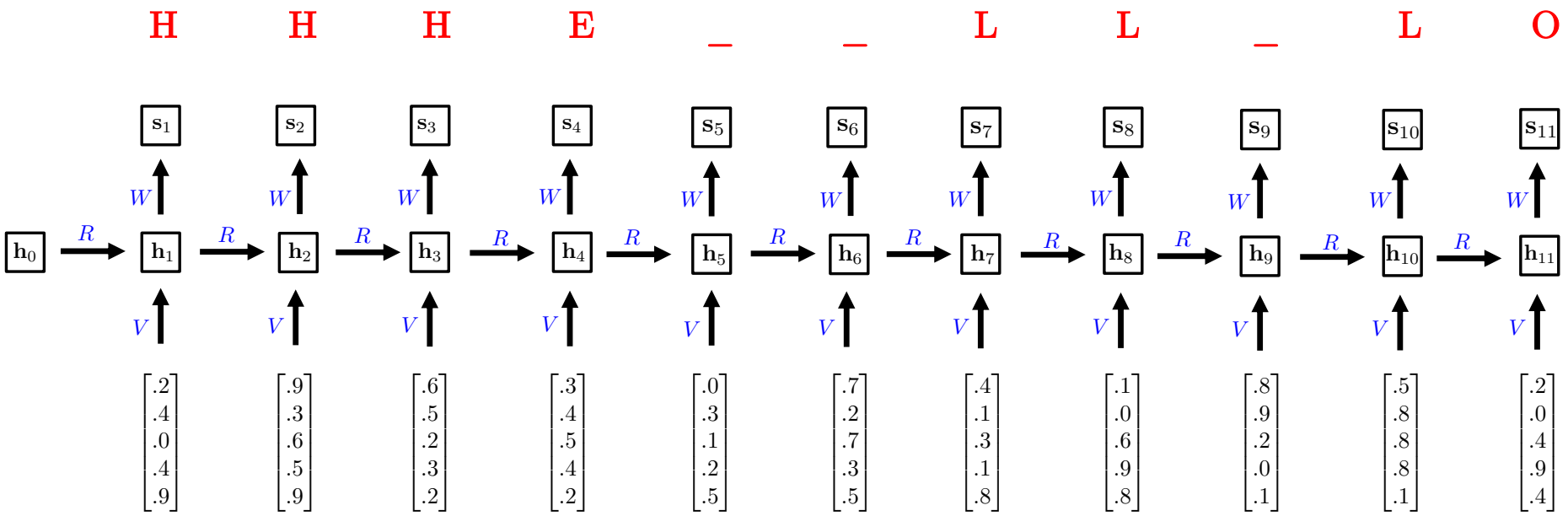




$$\begin{bmatrix}.2\\.4\\.0\\.4\\.9\end{bmatrix}\quad\begin{bmatrix}.9\\.3\\.6\\.5\\.9\end{bmatrix}\quad\begin{bmatrix}.6\\.5\\.2\\.3\\.2\end{bmatrix}\quad\begin{bmatrix}.3\\.4\\.5\\.4\\.2\end{bmatrix}\quad\begin{bmatrix}.0\\.3\\.1\\.2\\.5\end{bmatrix}\quad\begin{bmatrix}.7\\.2\\.7\\.3\\.5\end{bmatrix}\quad\begin{bmatrix}.4\\.1\\.3\\.1\\.8\end{bmatrix}\quad\begin{bmatrix}.1\\.0\\.6\\.9\\.8\end{bmatrix}\quad\begin{bmatrix}.8\\.9\\.2\\.0\\.1\end{bmatrix}\quad\begin{bmatrix}.5\\.8\\.8\\.8\\.1\end{bmatrix}\quad\begin{bmatrix}.2\\.0\\.4\\.9\\.4\end{bmatrix}$$

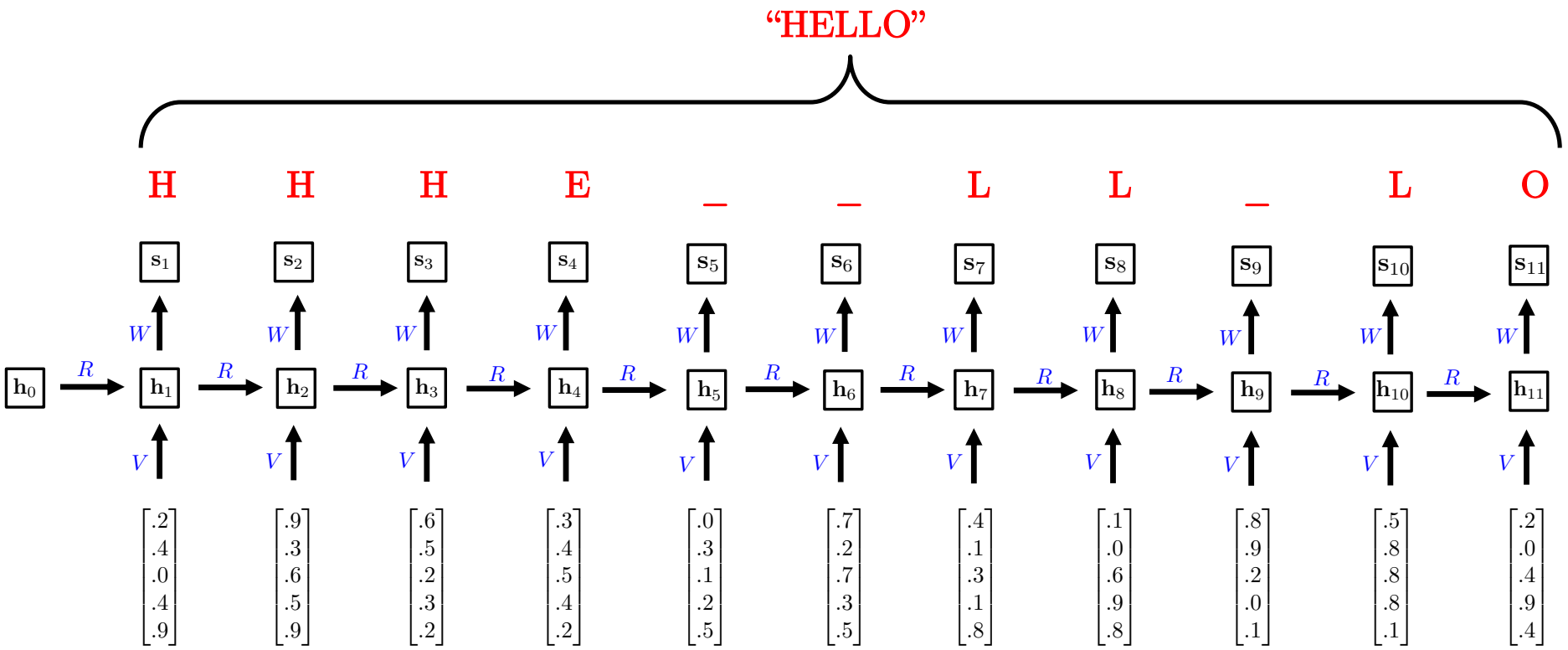
Inference

- Inference process :
  - Forward is done.



Inference

- Inference process :
  - The last layer at the very top is human hand-crafted :
    - Connectionist Temporal Classification (CTC)



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- **Machine Translation**
  - **Introduction**
  - Architecture
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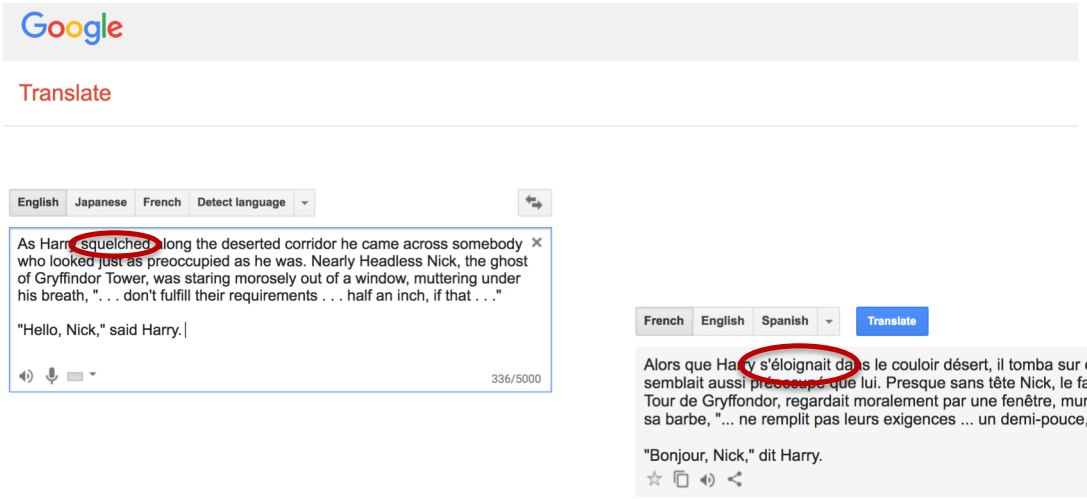
Neural machine translation

- Google Translate switched to Neural Machine Translation in Nov. 2016.
  - This led to a big improvement in quality !

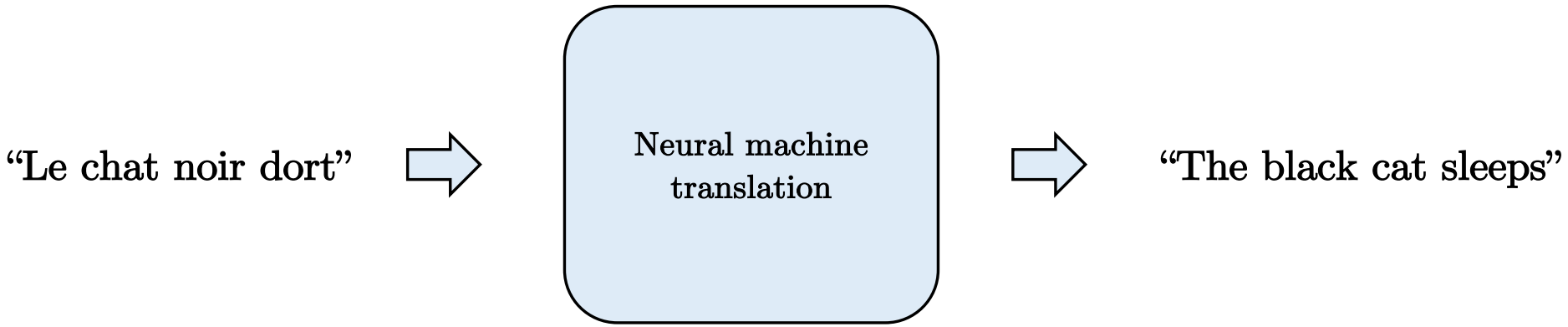
- Harry Potter and The Chamber of Secrets : English ⇒ French ⇒ English



Still far from professional translators, but some translators use it as first draft !

Neural machine translation

- The challenges of translation :
  - The words can appear in different order: Alignment problem.
  - Input and output sentences do not necessarily have the same number of words: Length problem.
  - Input and output sentences do not have the same number of words in their dictionary: Vocabulary problem.



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Architecture

- A translation system is composed of two recurrent neural networks :
  - Encoder network :
    - The encoder network will summarize the input sequence in language A with a vector.
  - Decoder network :
    - The decoder network will take the encoding vector representing the input sequence in language A and will decode it to an output sequence in language B.
- Full end-to-end machine learning systems :
  - No conceptual prior on languages – opposite to Chomsky's paradigm.
  - Big change in the NLP community !

Architecture

Step 1: Take a sentence in French and encode it into a vector h of size 200.

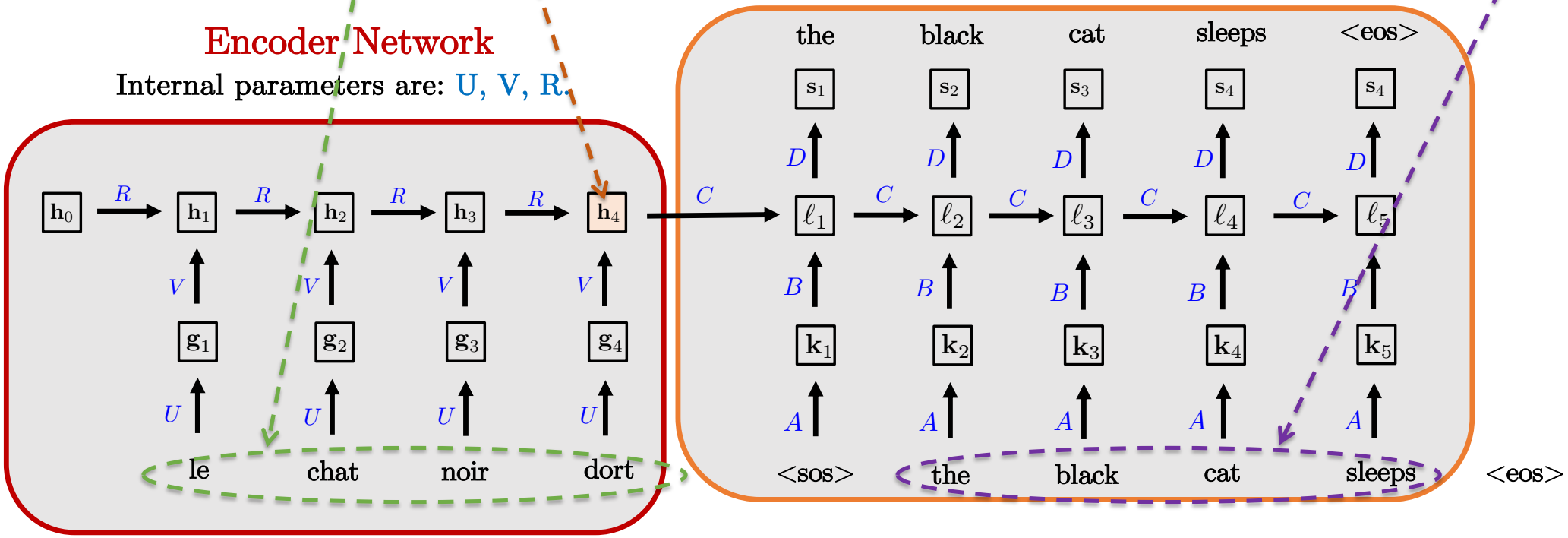
Step 2: Take the vector created by the encoder and use it to generate a sentence in English.

Encoder Network

Internal parameters are: U, V, R.

Decoder Network

Internal parameters are: A, B, C, D.



Architecture

- Dictionaries : We have two vocabularies :
  - French vocabulary has 35,000 words.
    - Each French word is a one-hot-vector with 35,000 entries.
  - English vocabulary has 32,000 words.
    - Each English word is a one-hot-vector with 32,000 entries.

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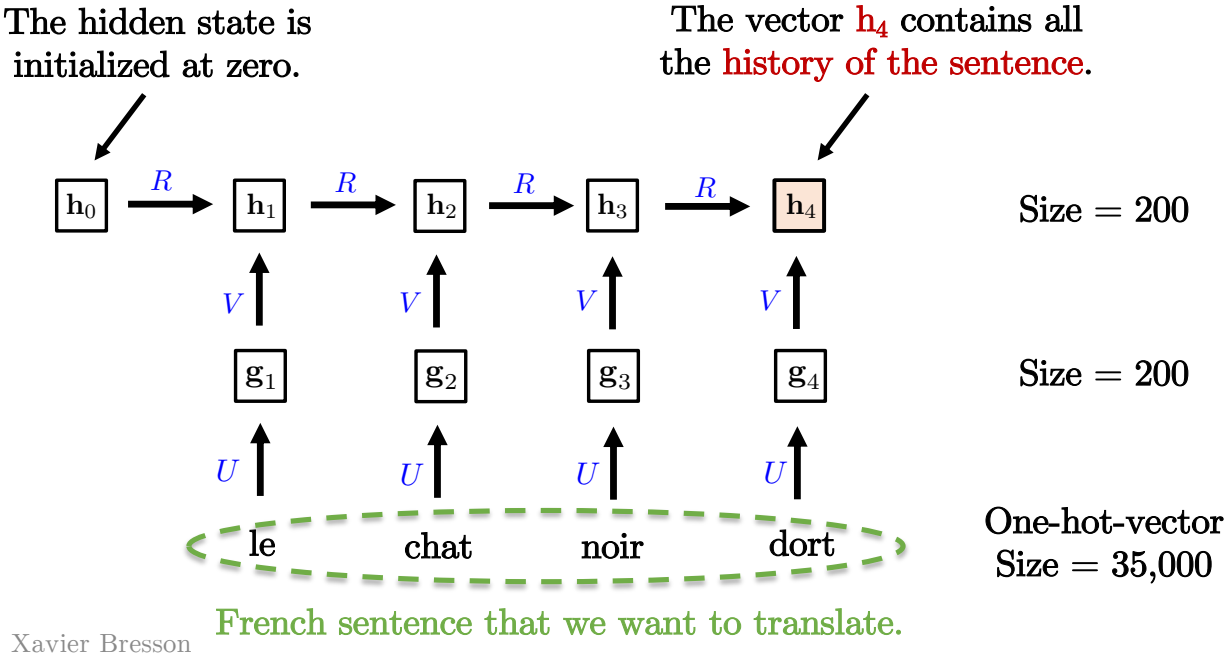
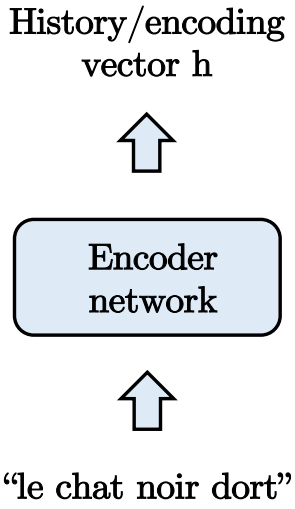
Inference

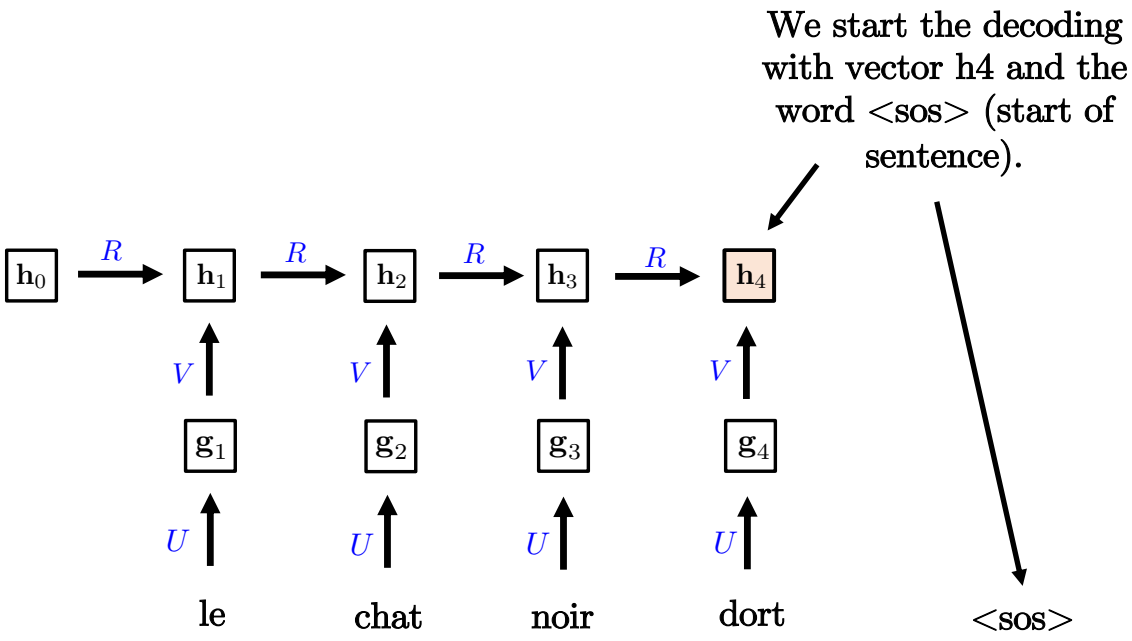
- The network has been trained, let us use it for inference.
- First step of inference:
  - Encode the input sequence with an history vector.

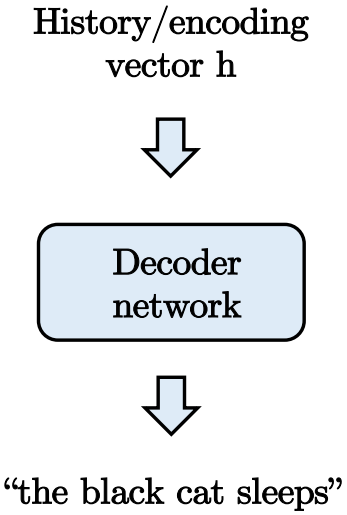




Inference

- Second step of inference:
  - Decode the encoding/history vector into an output sequence.





Inference

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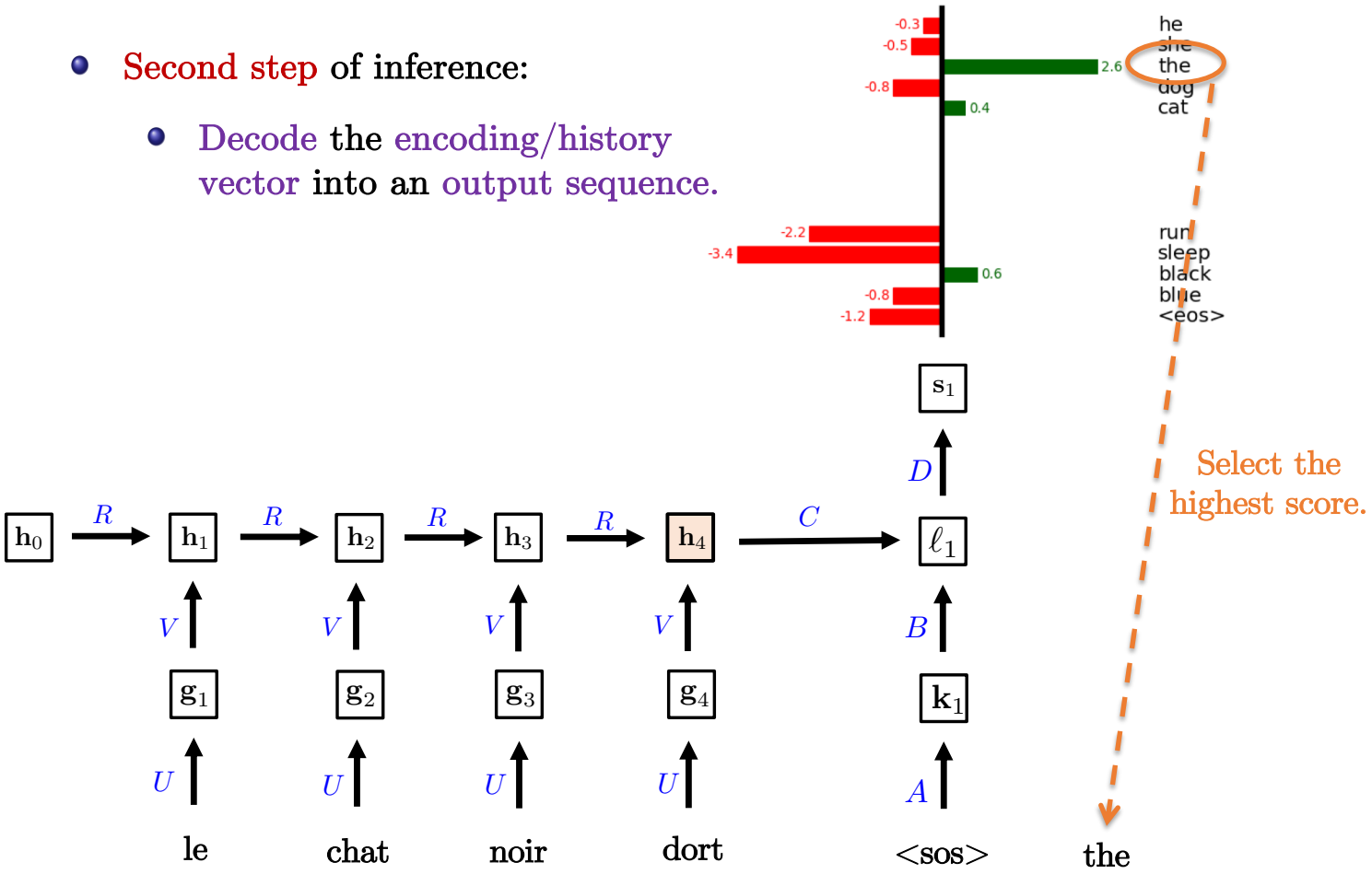

Inference

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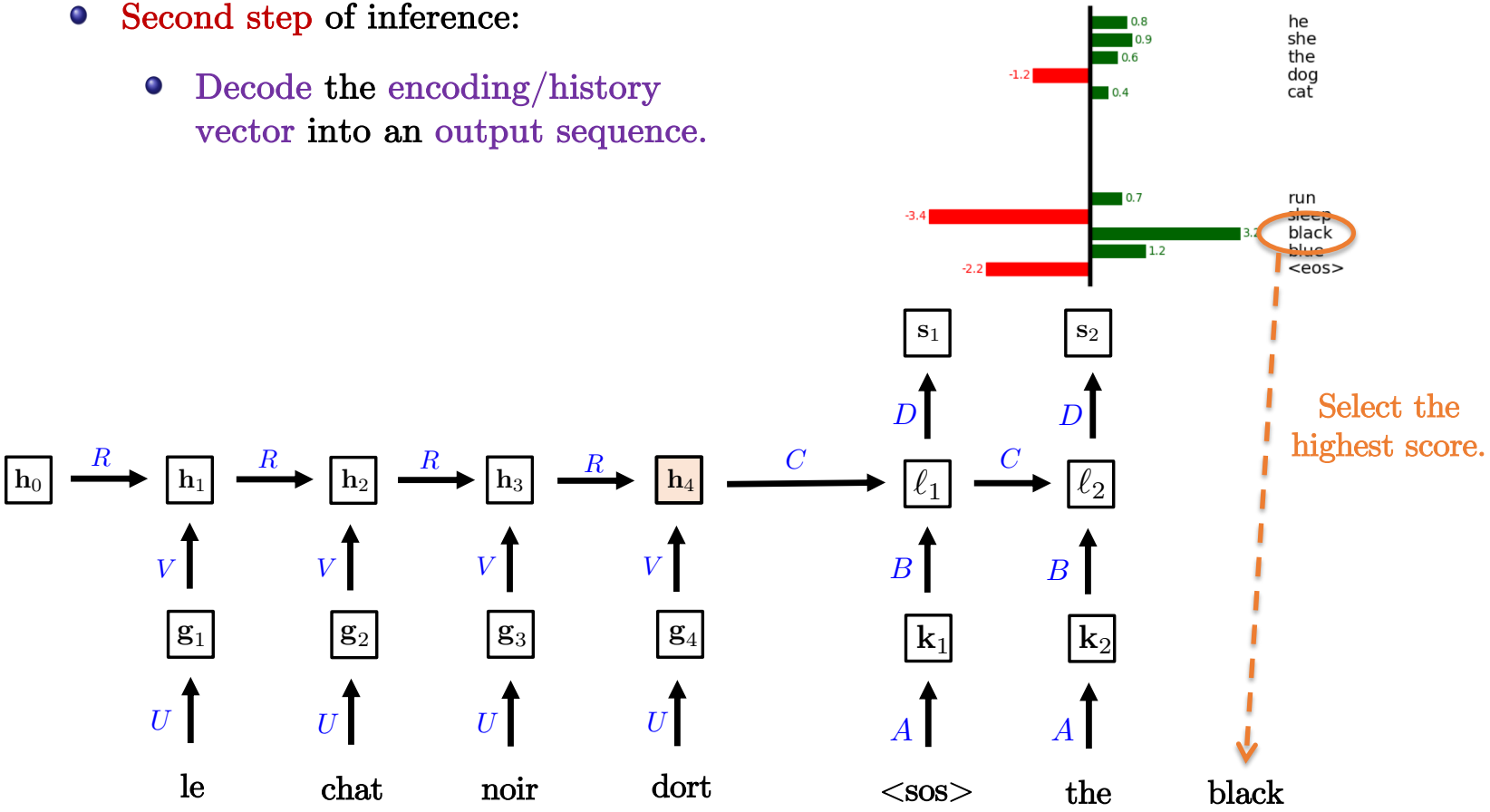

Inference

- Second step of inference:
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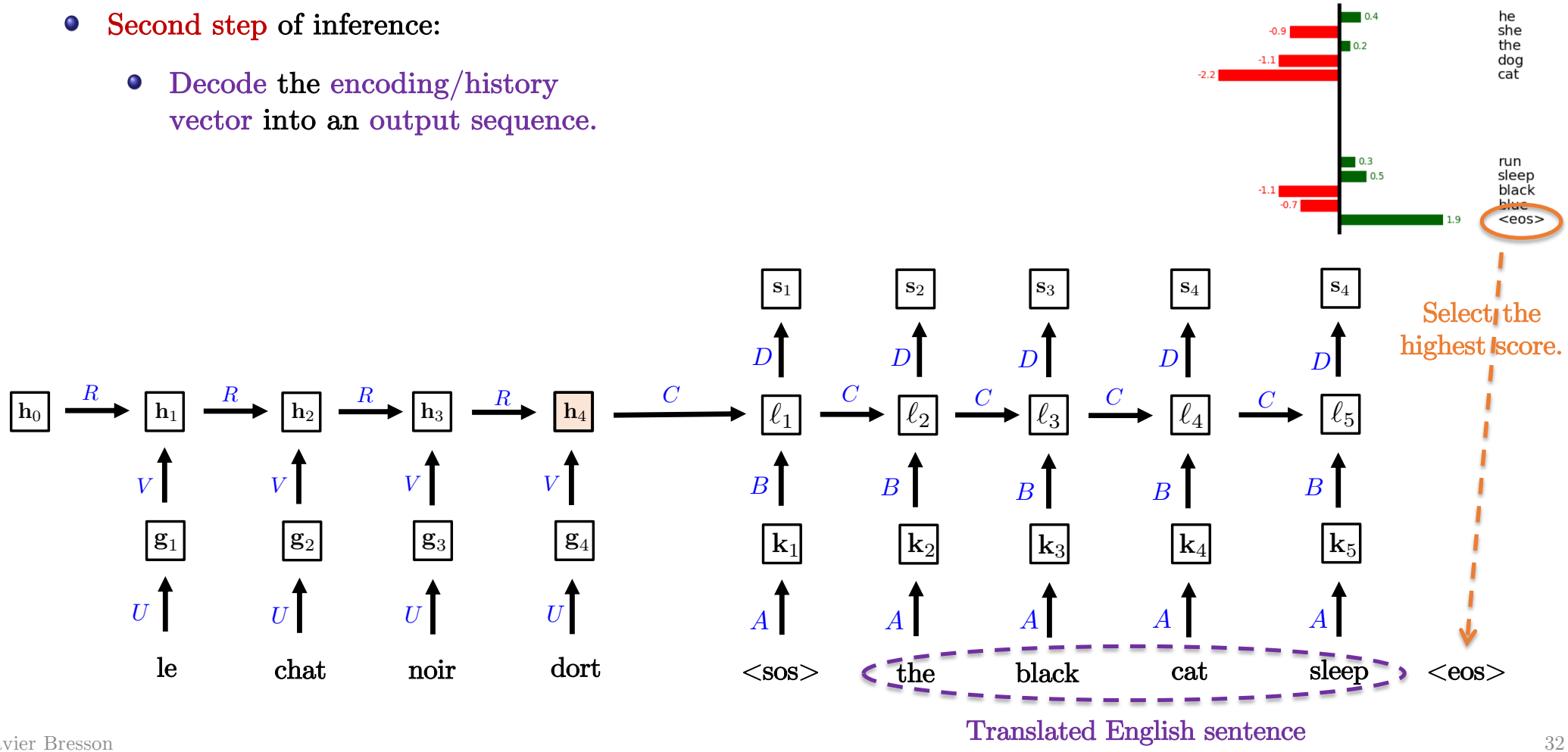

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Training

- Let us train the network with 10 million French ⇒ English sentences :

Sentence 1	le chat noir dort	<sos> the black cat sleep <eos>
Sentence 2	hier je suis aller a la plage	<sos> yesterday I went to the beach <eos>
Sentence 3	je m'appelle thomas	<sos> my name is thomas <eos>
⋮	⋮	⋮
Sentence 10,000,000	tu est un tres bon joueur de tennis	<sos> you are a very good tennis player <eos>

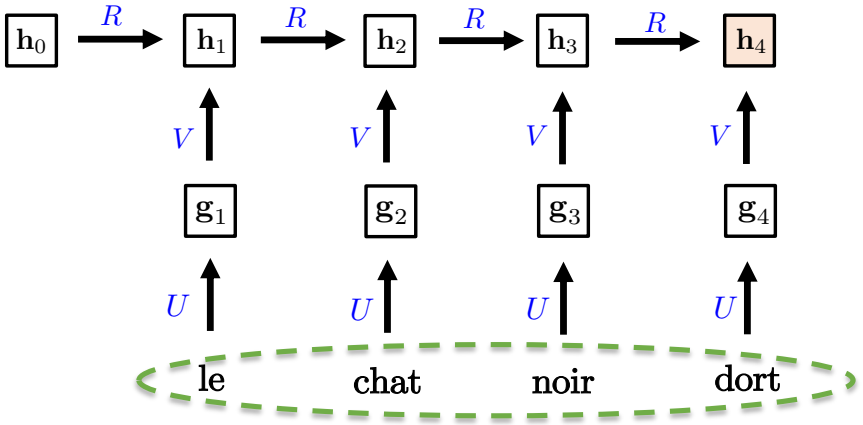
Training

- Let us feed the 1st French ⇒ English sentence :

Labels: the, black, cat, sleeps, <eos>

Translated English sentence 1

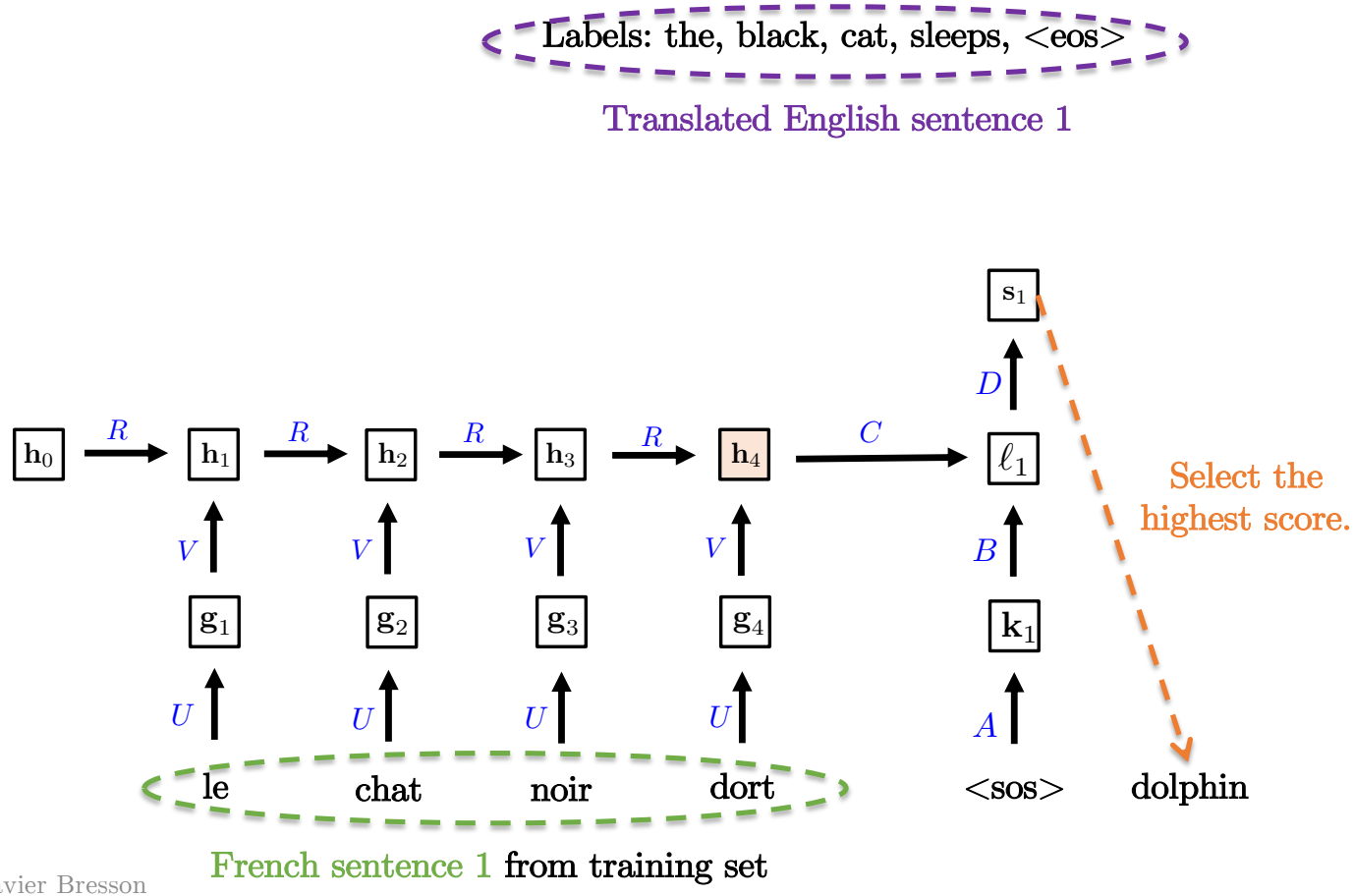
The hidden state is initialized at zero.



French sentence 1 from training set

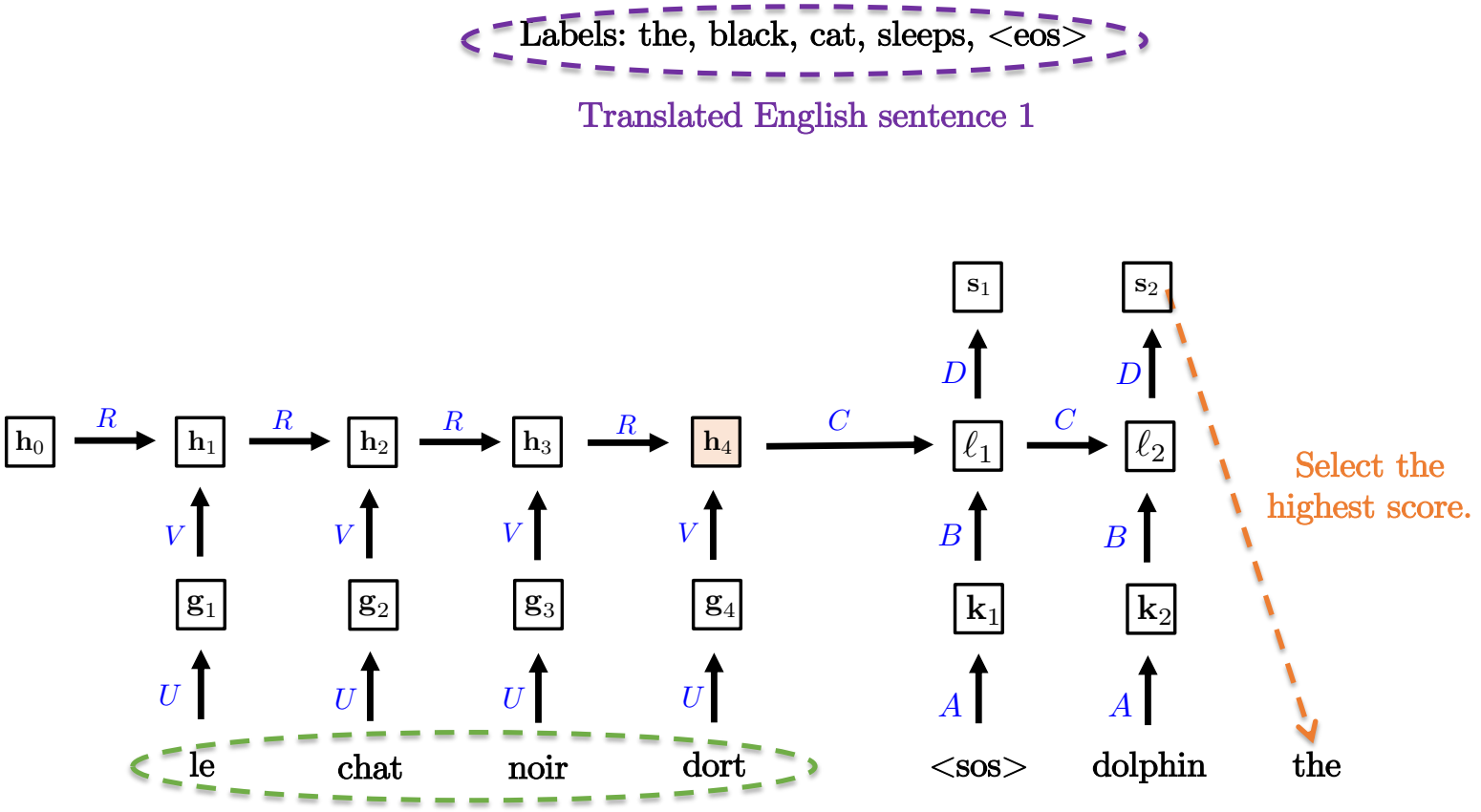
Training

- Let us feed the 1st French ⇒ English sentence :



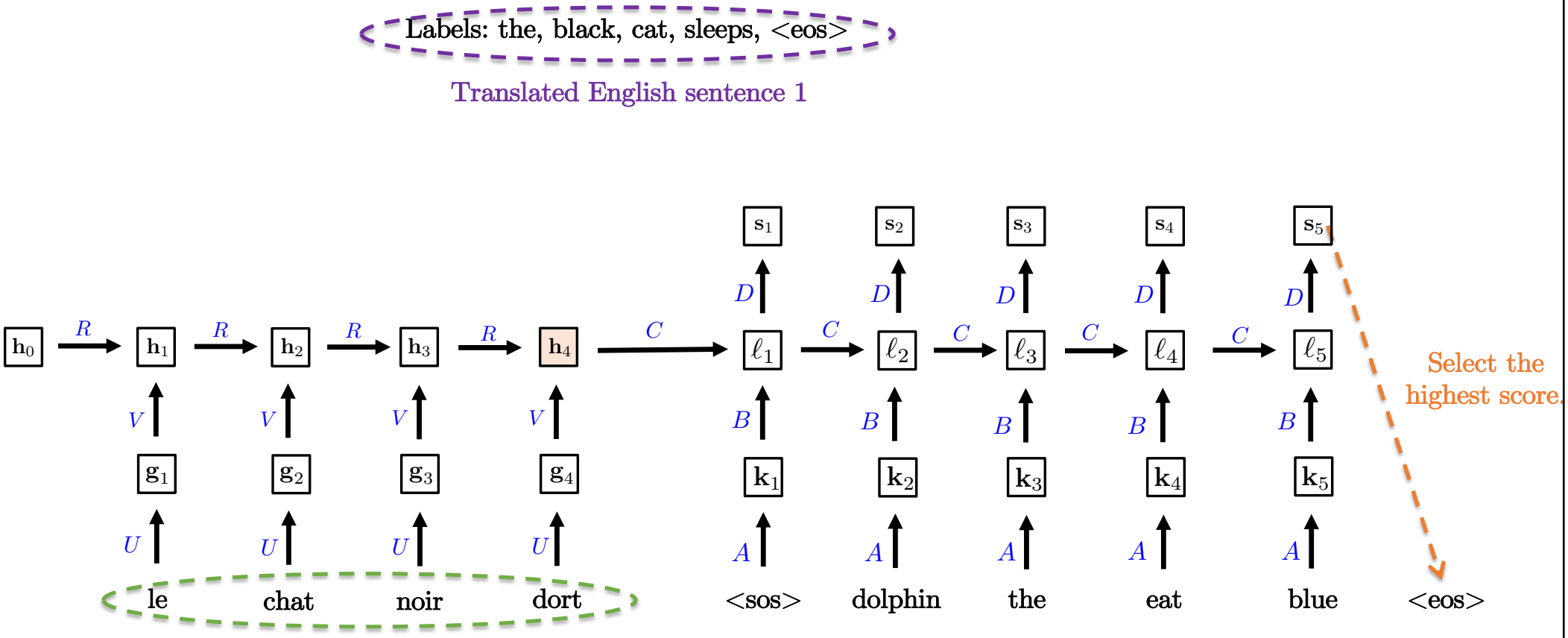
Training

- Let us feed the 1st French ⇒ English sentence :



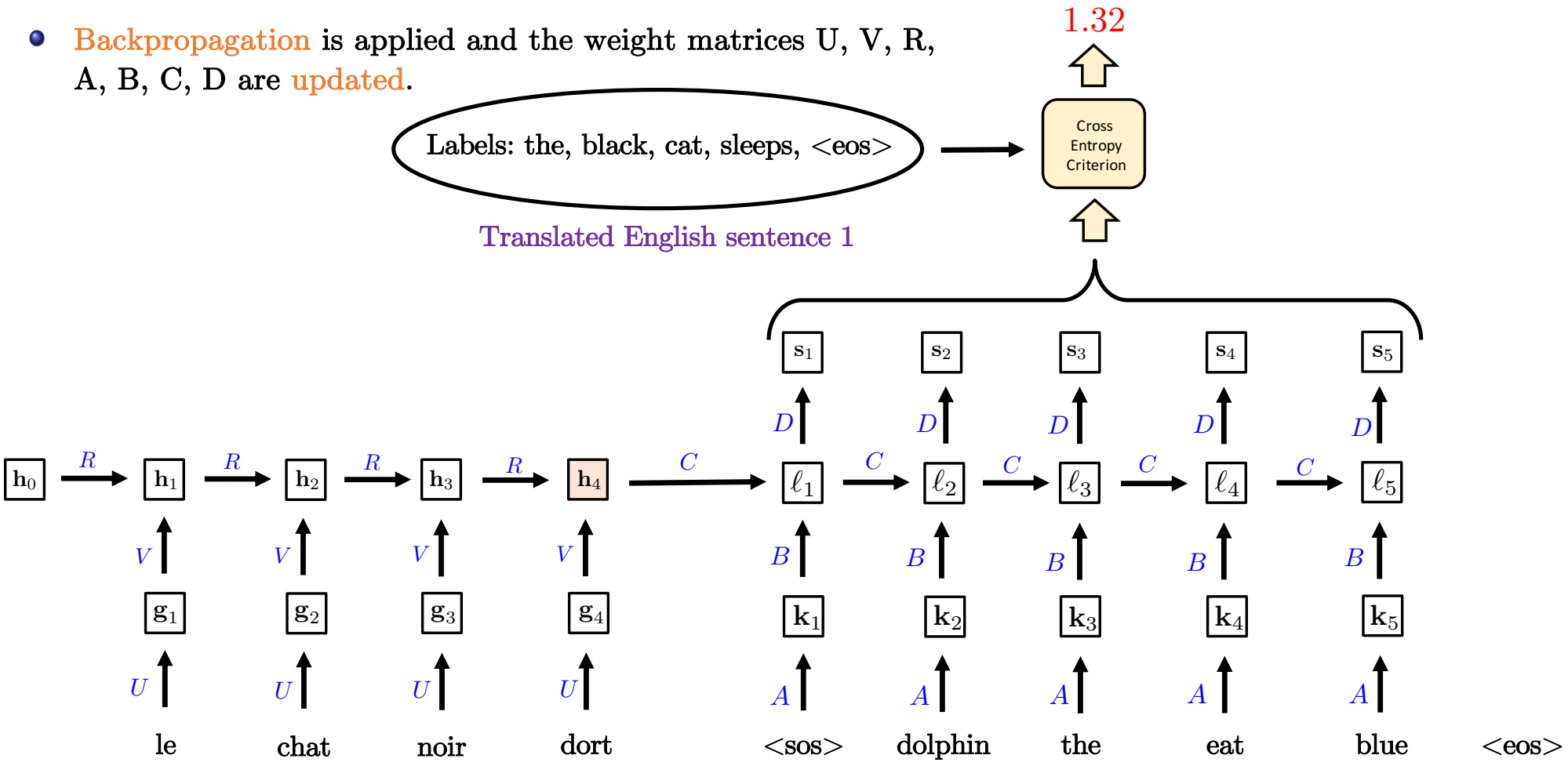
Training

- Let us feed the 1st French ⇒ English sentence :



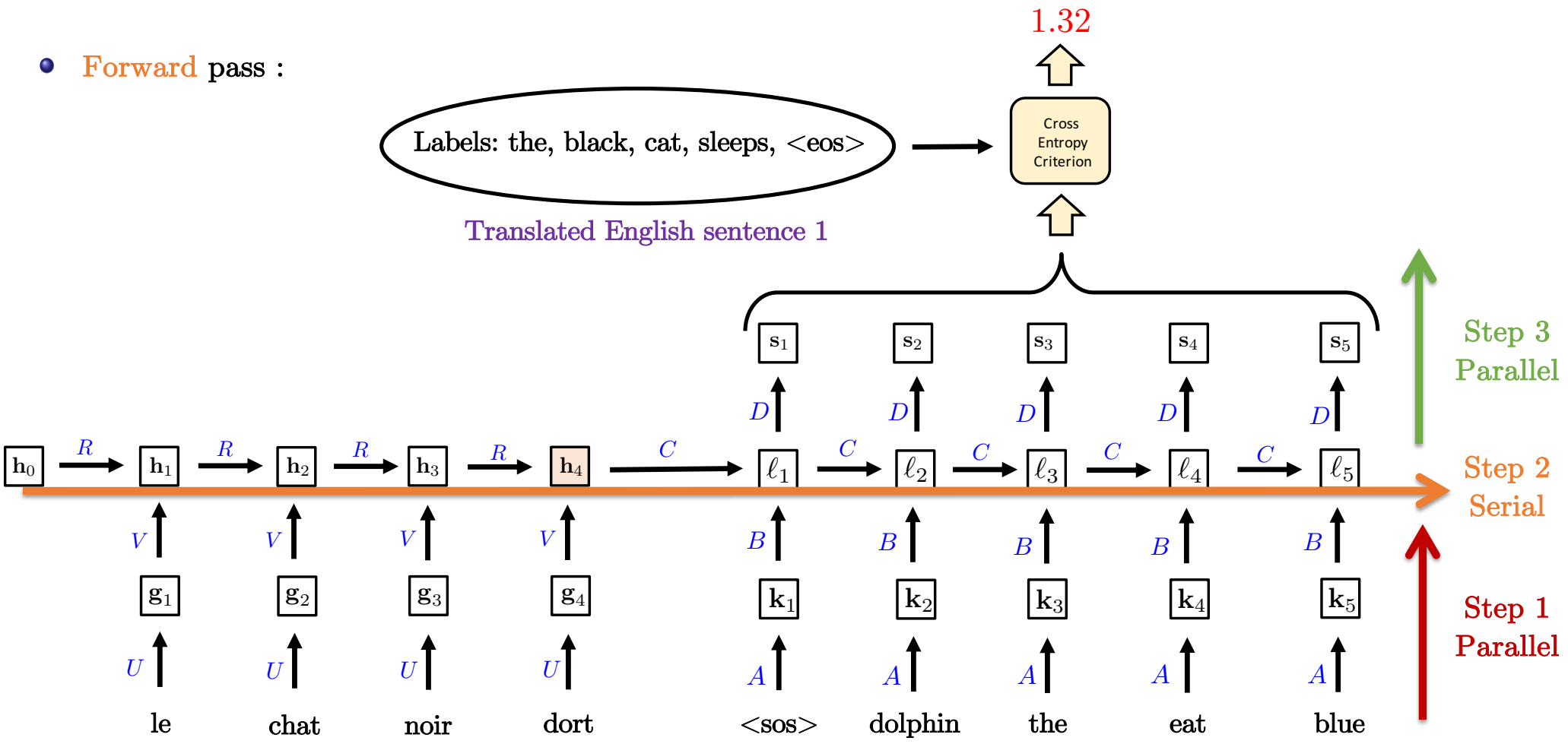
Training

- Backpropagation is applied and the weight matrices U, V, R, A, B, C, D are updated.



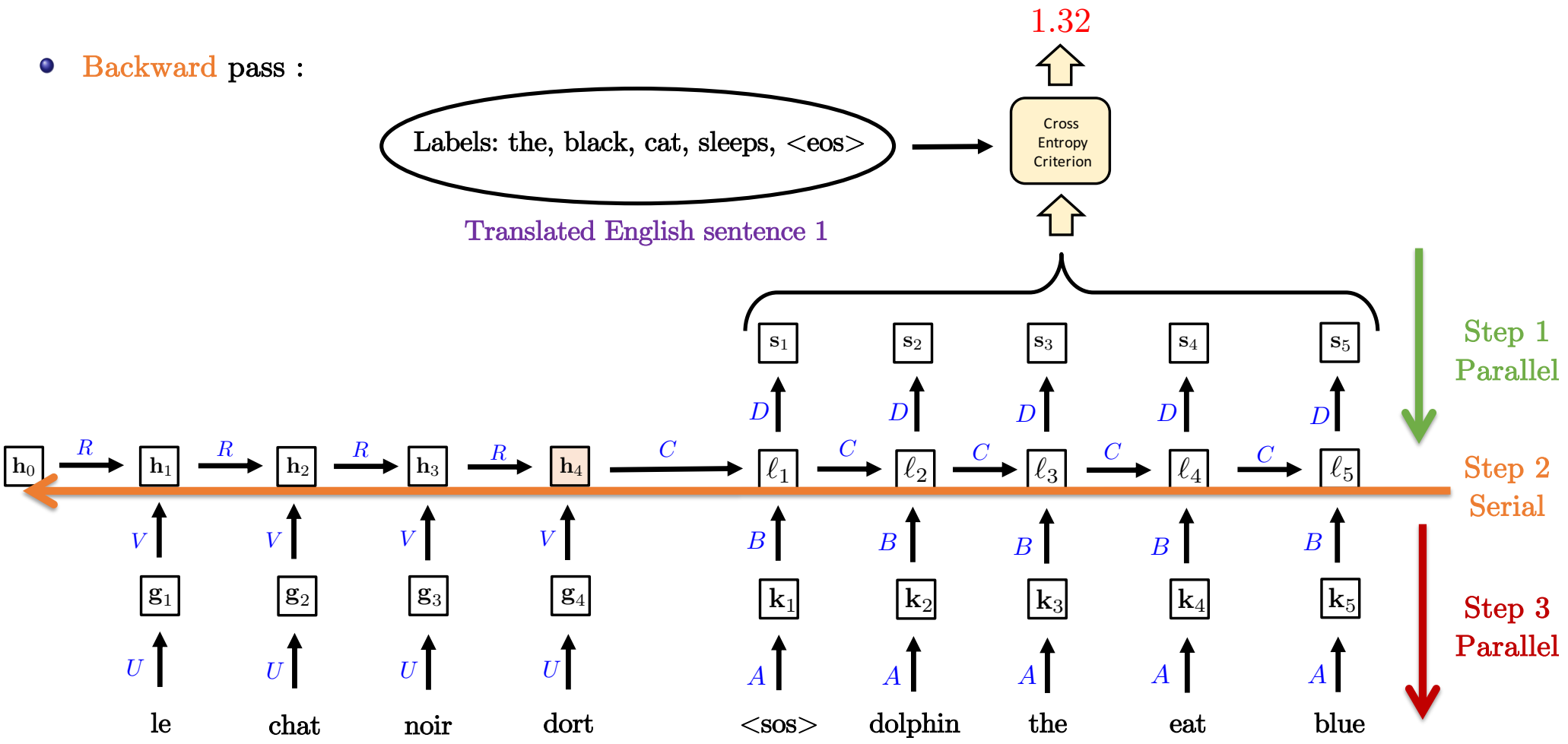
Training

- Forward pass :



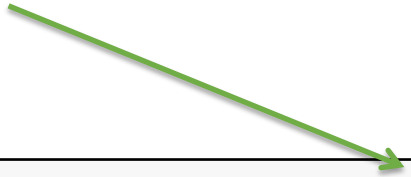
Training

- Backward pass :



Training

- State-of-the-art machine translation machine :
  - Stack 10 layers of bi-directional LSTM :

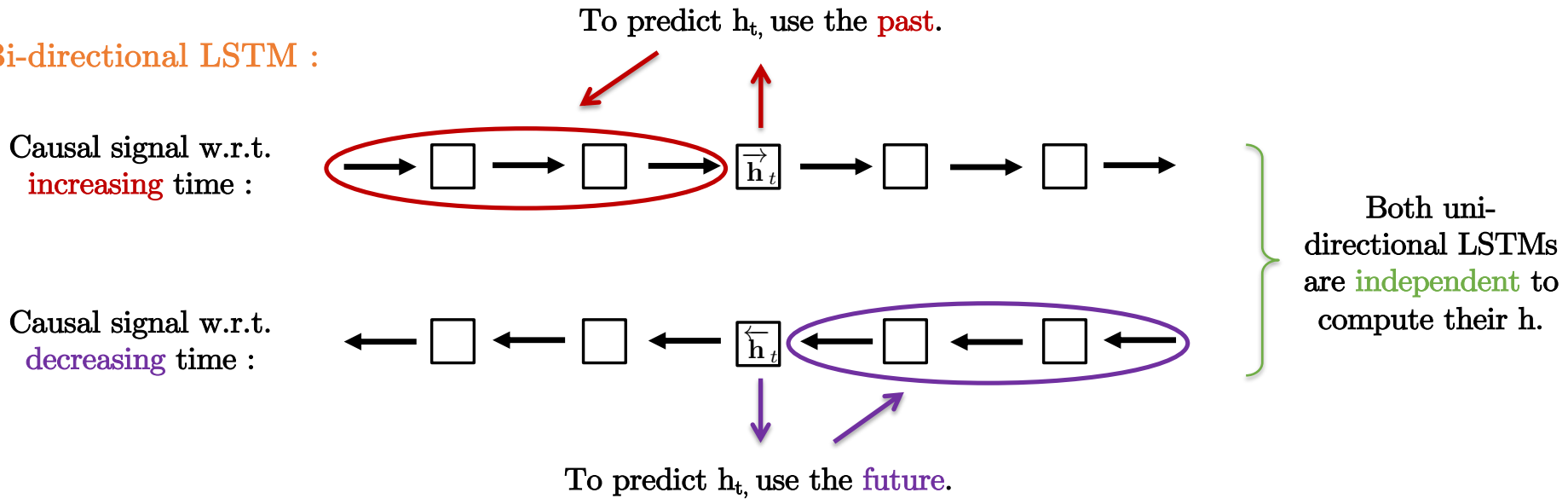


```
net = nn.LSTM( hidden_size , hidden_size , bidirectional=True )
```

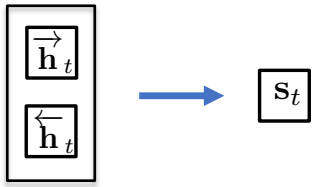
  - Use an attention mechanism.

Training

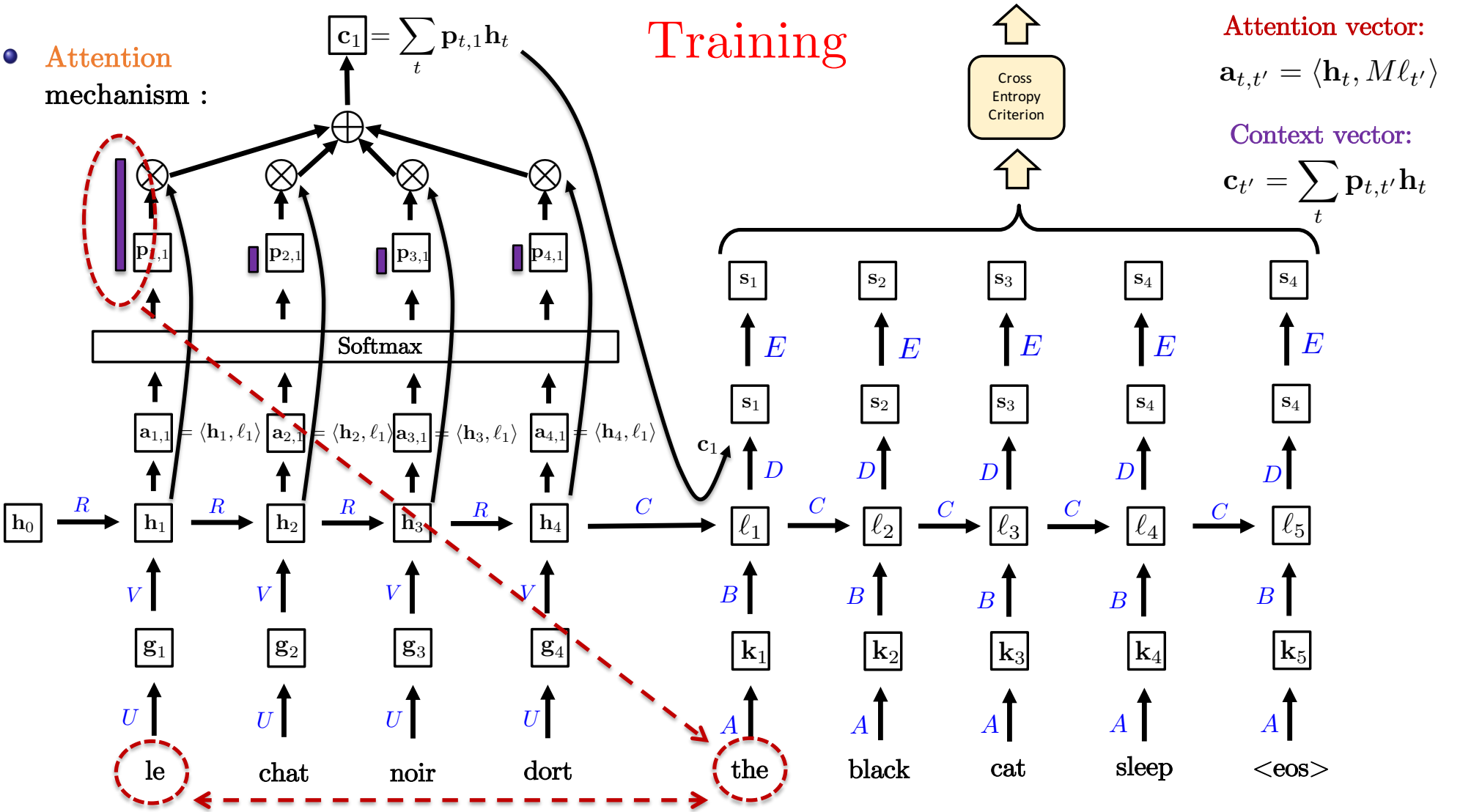
- Bi-directional LSTM :



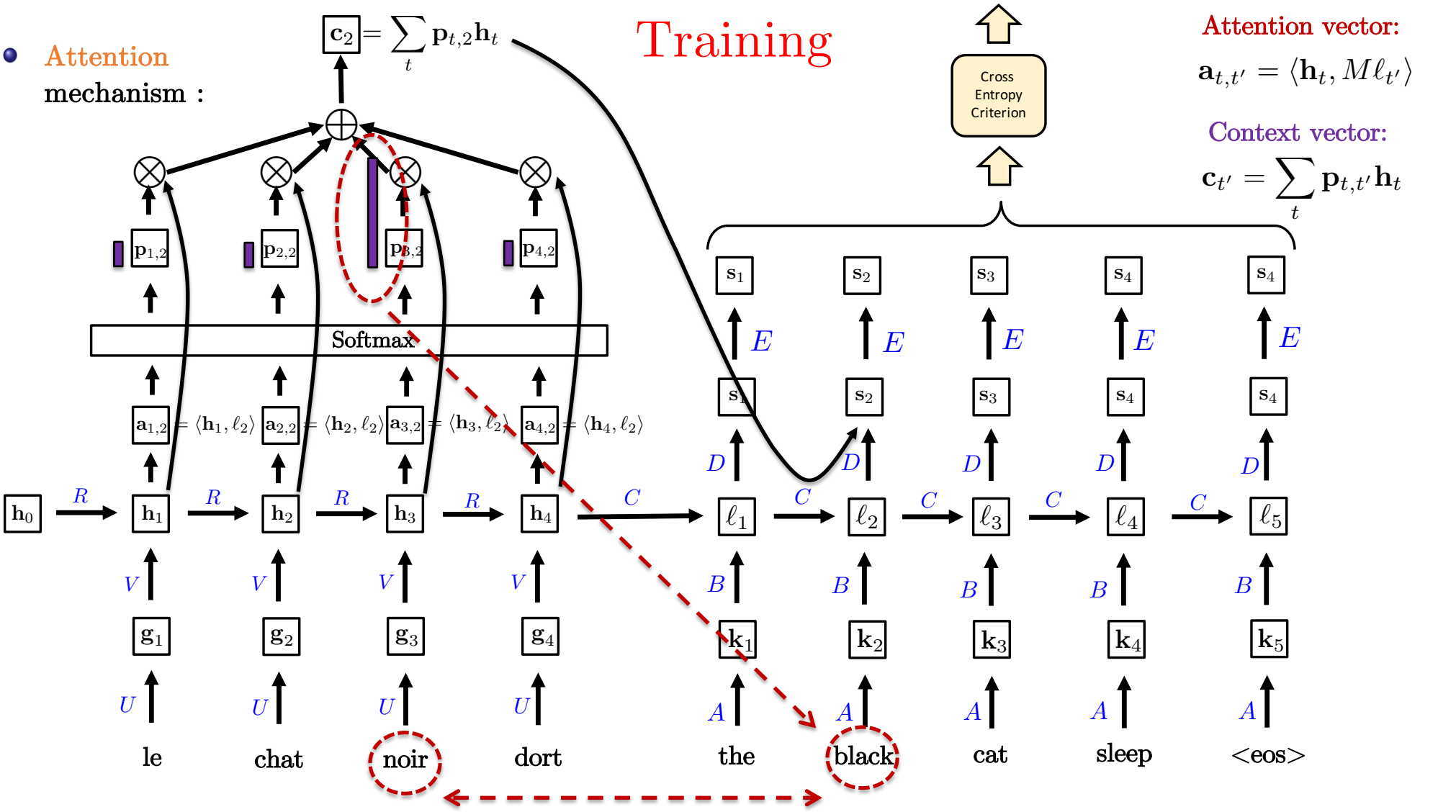
Combine both hidden vectors h to better solve NLP tasks (e.g. Q&A)



- Attention mechanism :



- Attention mechanism :



End of RNNs ?

- Attention neural networks are taking over NLP !
  - 2019 breakthrough in AI

Attention Is All You Need

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Abstract

The dominant sequence transduction models are based on complex recurrent or convolutional neural networks that include an encoder and a decoder. The best performing models also connect the encoder and decoder through an attention mechanism. We propose a new simple network architecture, the Transformer, based solely on attention mechanisms, dispensing with recurrence and convolutions entirely. Experiments on two machine translation tasks show these models to be superior in quality while being more parallelizable and requiring significantly less time to train. Our model achieves 28.4 BLEU on the WMT 2014 English-to-German translation task, improving over the existing best results, including ensembles, by over 2 BLEU. On the WMT 2014 English-to-French translation task, our model establishes a new single-model state-of-the-art BLEU score of 41.8 after training for 3.5 days on eight GPUs, a small fraction of the training costs of the best models from the literature. We show that the Transformer generalizes well to other tasks by applying it successfully to English constituency parsing both with large and limited training data.

Questions?