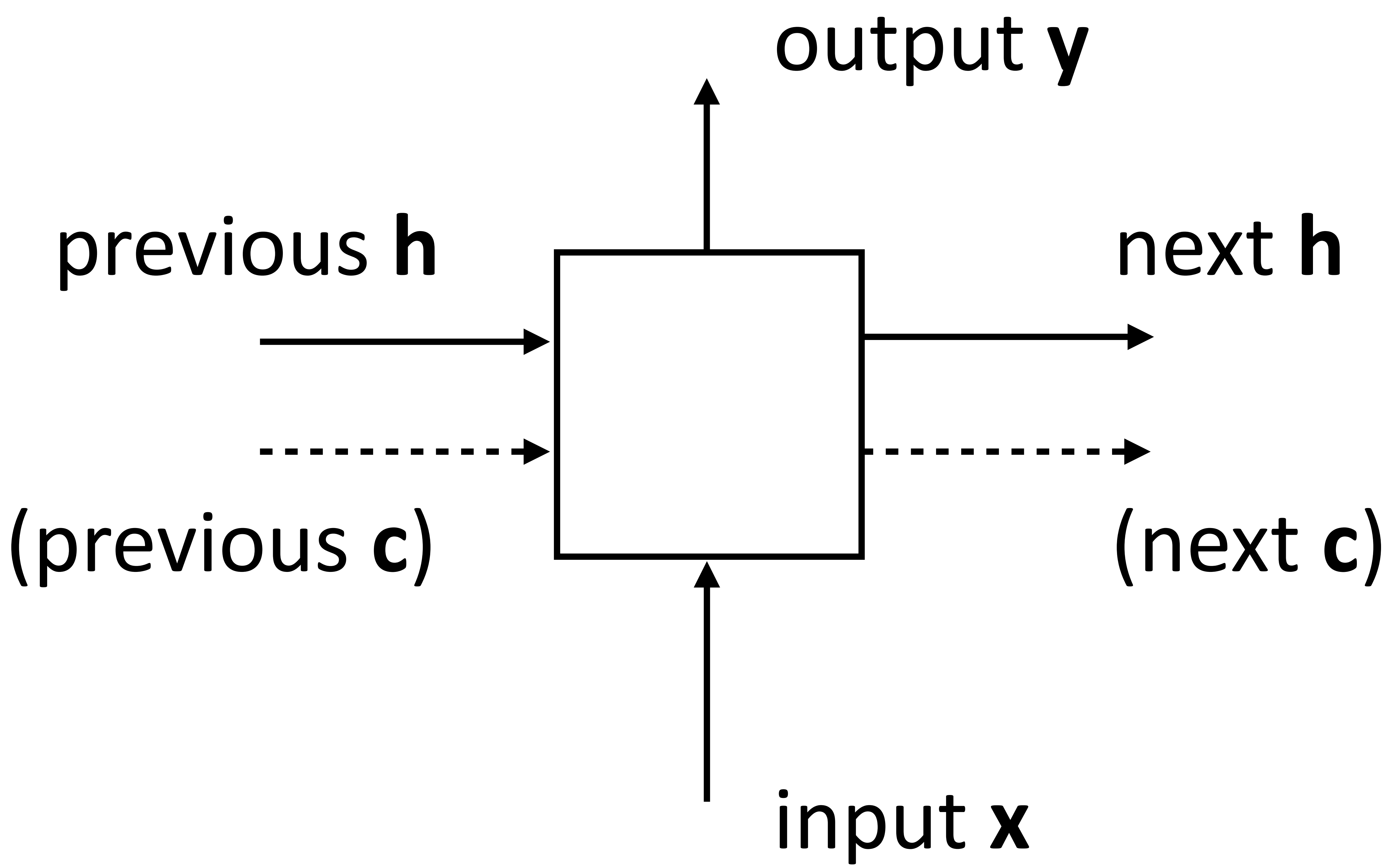
Lecture 9: CNNs, Neural CRFs

Alan Ritter

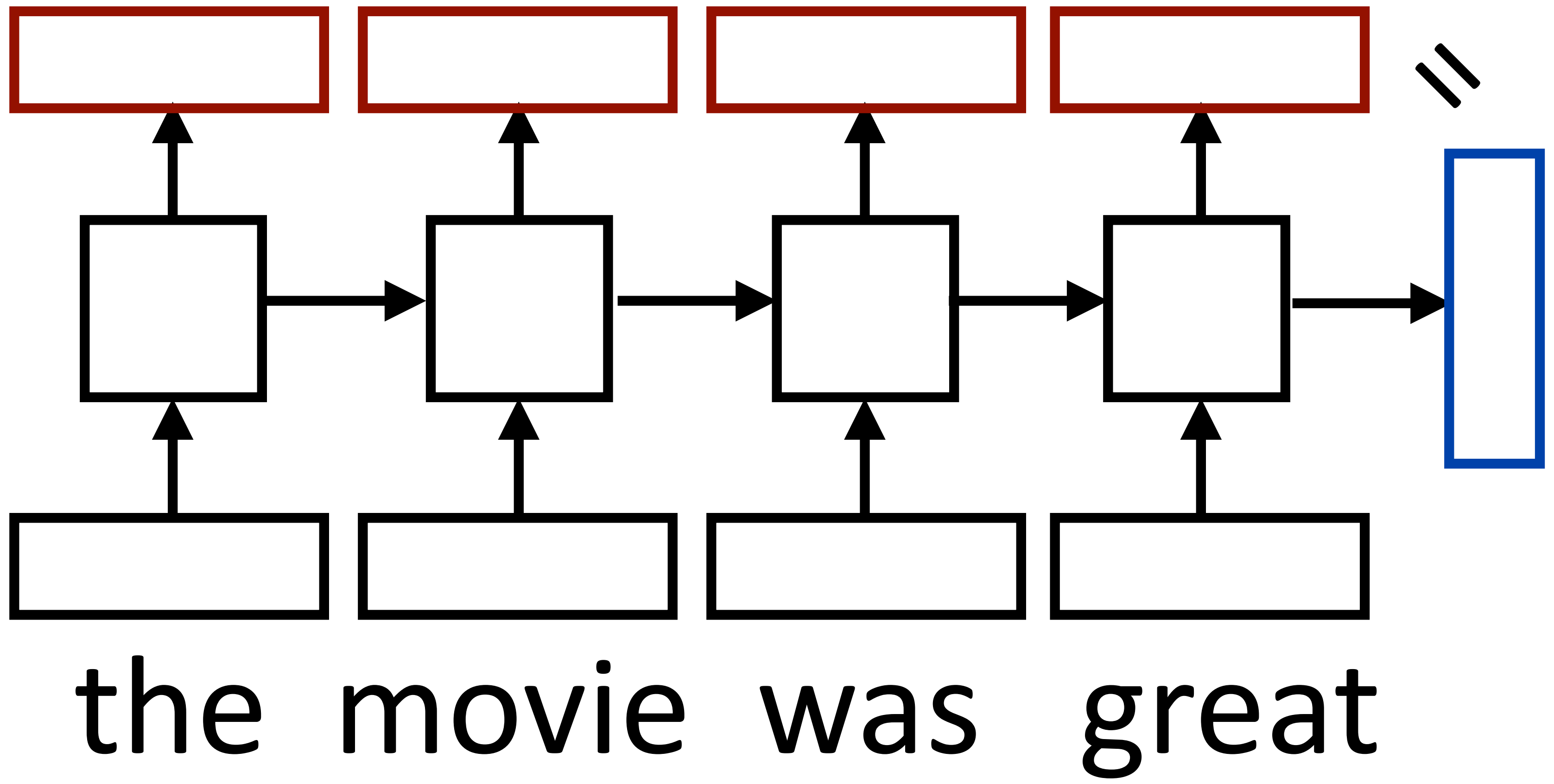
(many slides from Greg Durrett)

Recall: RNNs

- Cell that takes some input **x**, has some hidden state **h**, and updates that hidden state and produces output **y** (all vector-valued)



Recall: RNN Abstraction



- Encoding of the sentence — can pass this a decoder or make a classification decision about the sentence
- Encoding of each word — can pass this to another layer to make a prediction (can also pool these to get a different sentence encoding)
- RNN can be viewed as a transformation of a sequence of vectors into a sequence of context-dependent vectors

What can LSTMs model?

- Sentiment
  - Encode one sentence, predict
- Language models
  - Move left-to-right, per-token prediction
- Translation
  - Encode sentence + then decode, use token predictions for attention weights (next lecture)

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- Translation
  - Encode sentence + then decode, use token predictions for attention weights (next lecture)
- Textual entailment
  - Encode two sentences, predict

Natural Language Inference

Premise	Hypothesis
A boy plays in the snow	A boy is outside

Natural Language Inference

Premise		Hypothesis
A boy plays in the snow	*entails*	A boy is outside

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- Long history of this task: "Recognizing Textual Entailment" challenge in 2006 (Dagan, Glickman, Magnini)

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- Long history of this task: "Recognizing Textual Entailment" challenge in 2006 (Dagan, Glickman, Magnini)
- Early datasets: small (hundreds of pairs), very ambitious (lots of world knowledge, temporal reasoning, etc.)

SNLI Dataset

- Show people captions for (unseen) images and solicit entailed / neural / contradictory statements
- >500,000 sentence pairs

Bowman et al. (2015)

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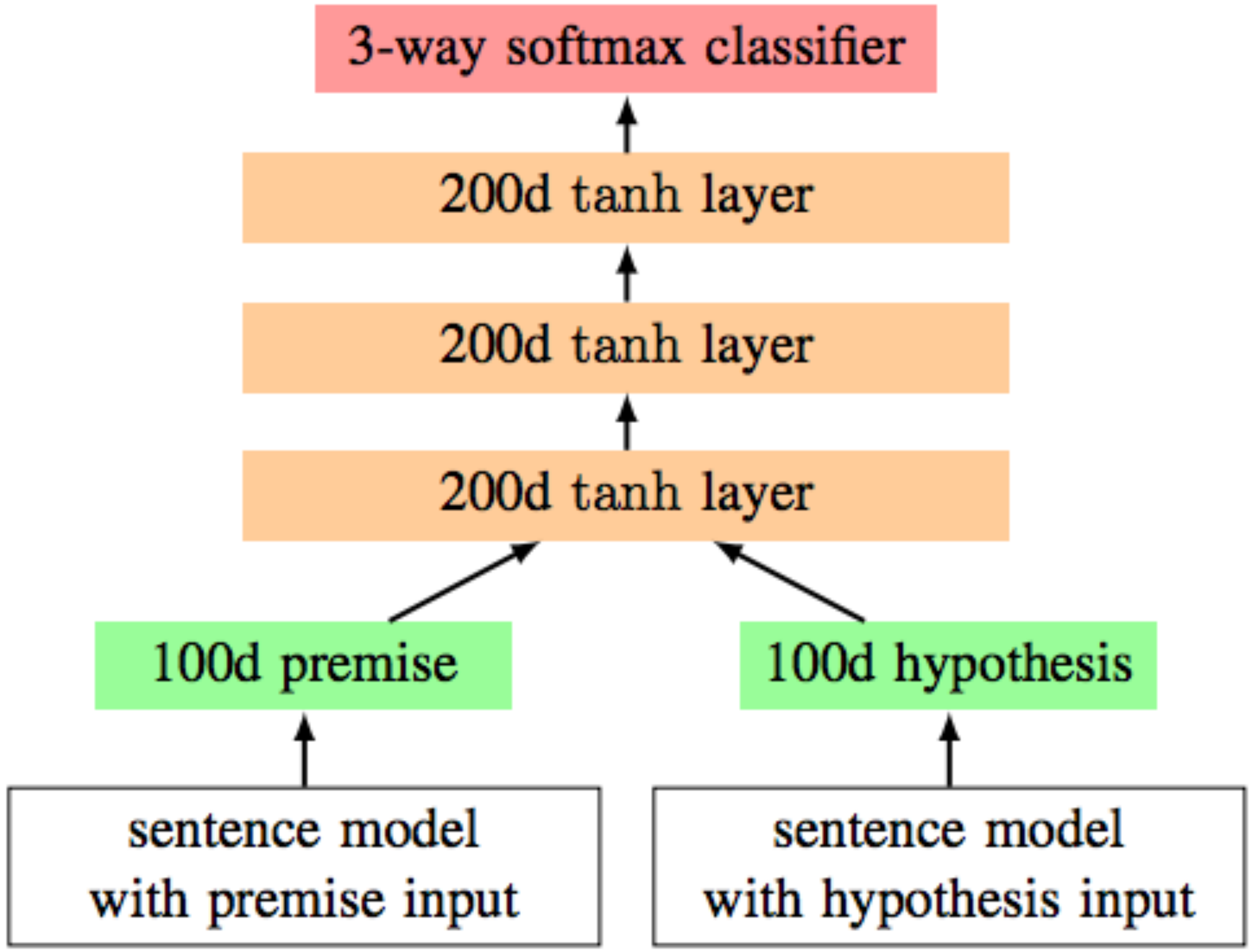

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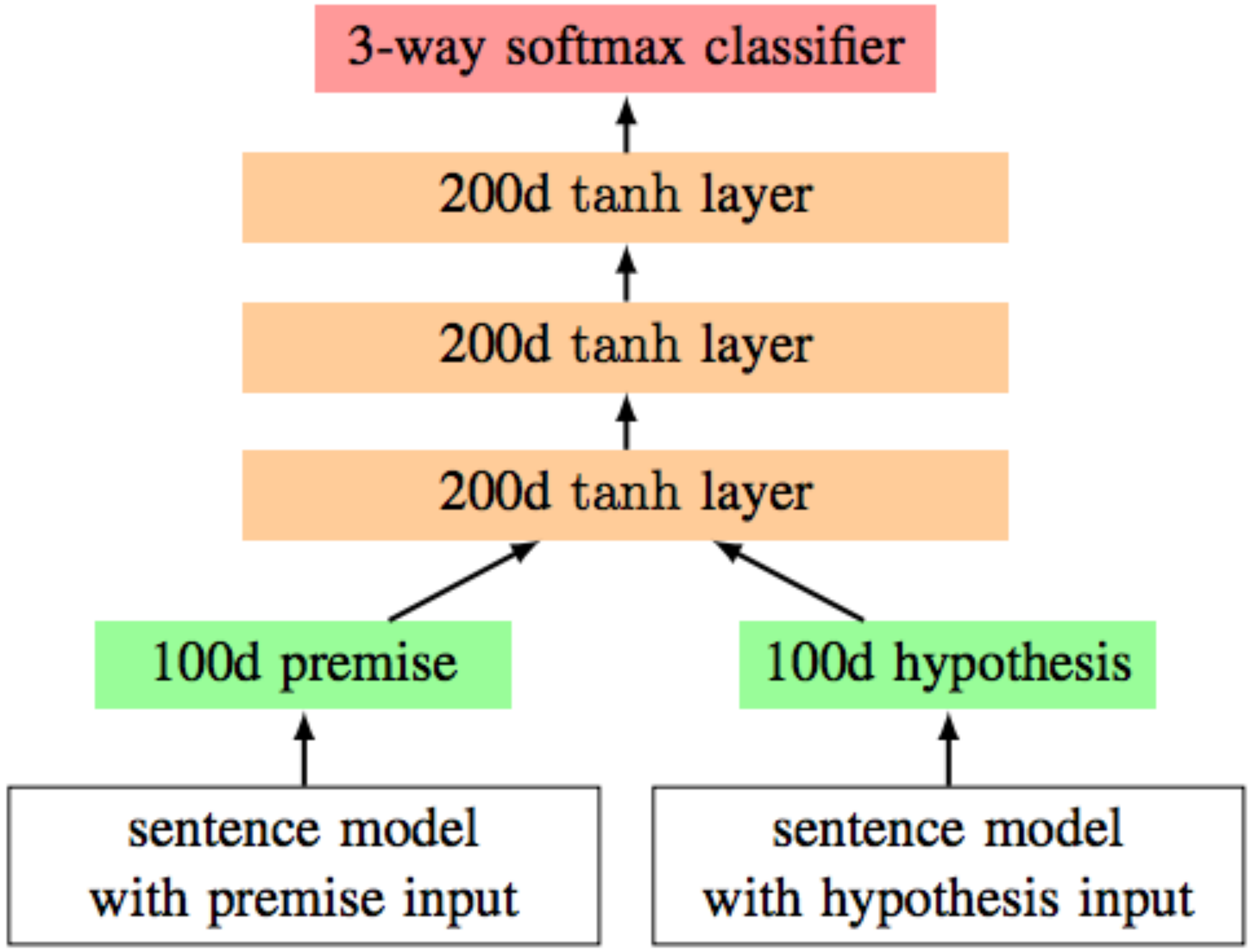
100D LSTM: 78% accuracy



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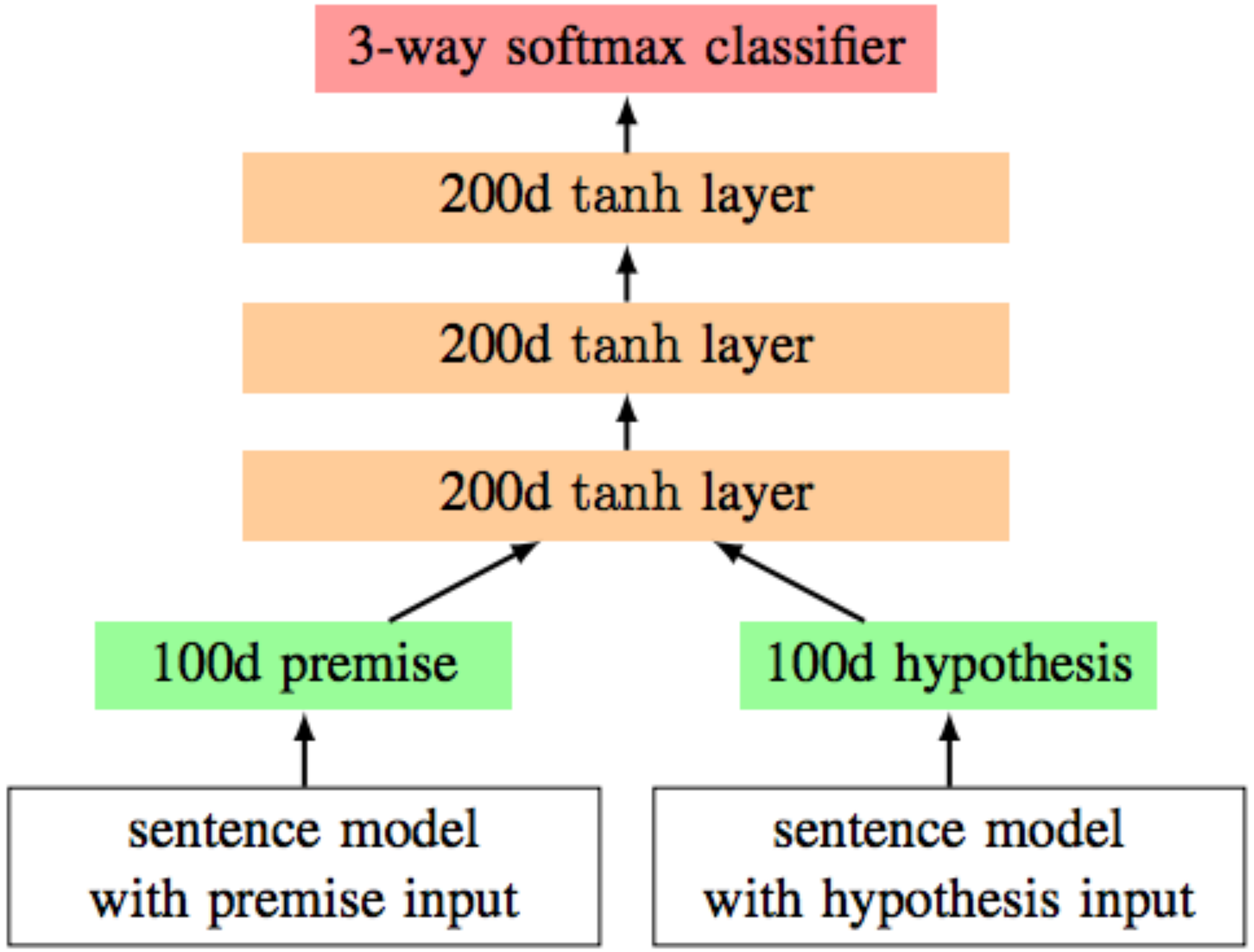
(Bowman et al., 2016)



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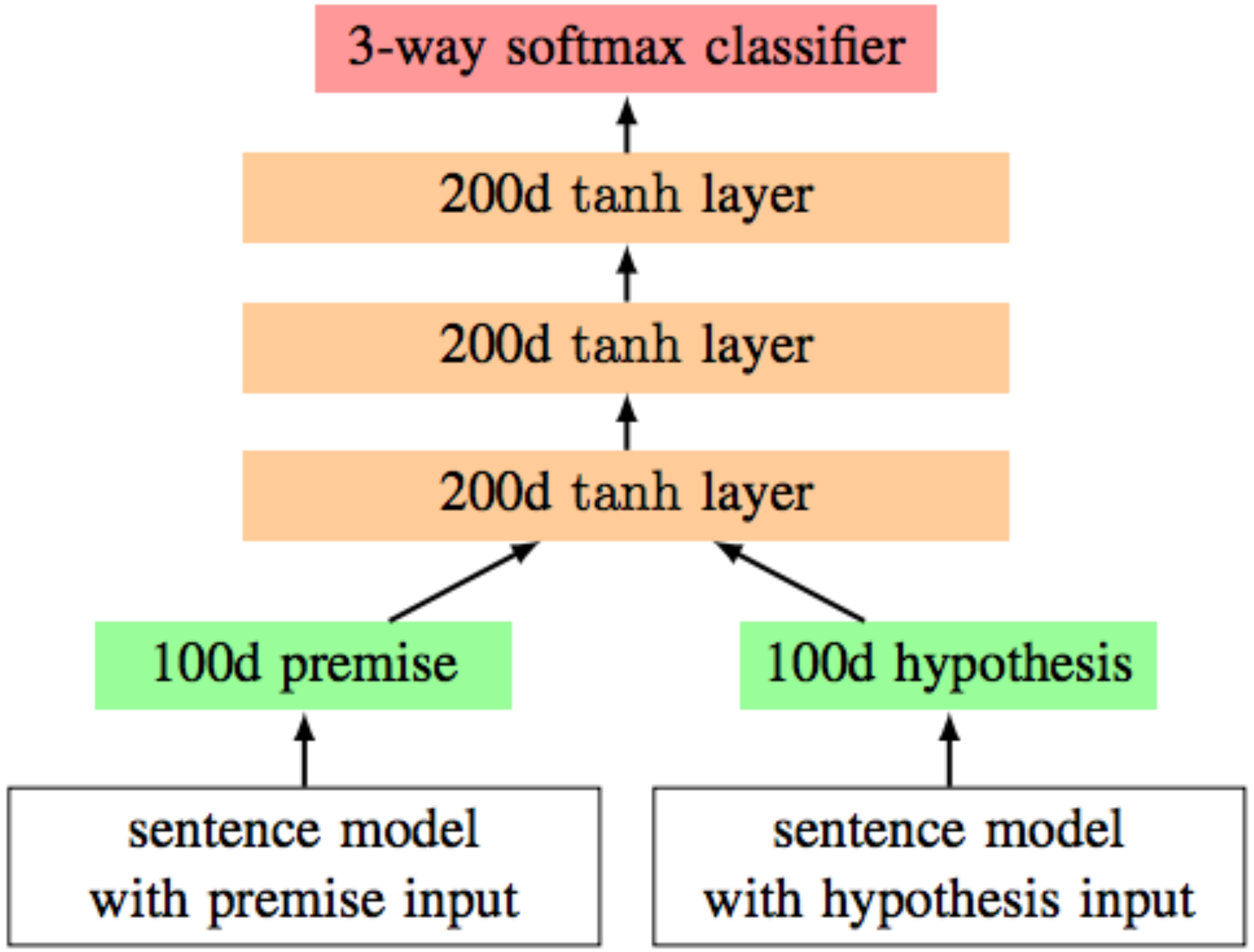
300D BiLSTM: 83% accuracy

(Liu et al., 2016)



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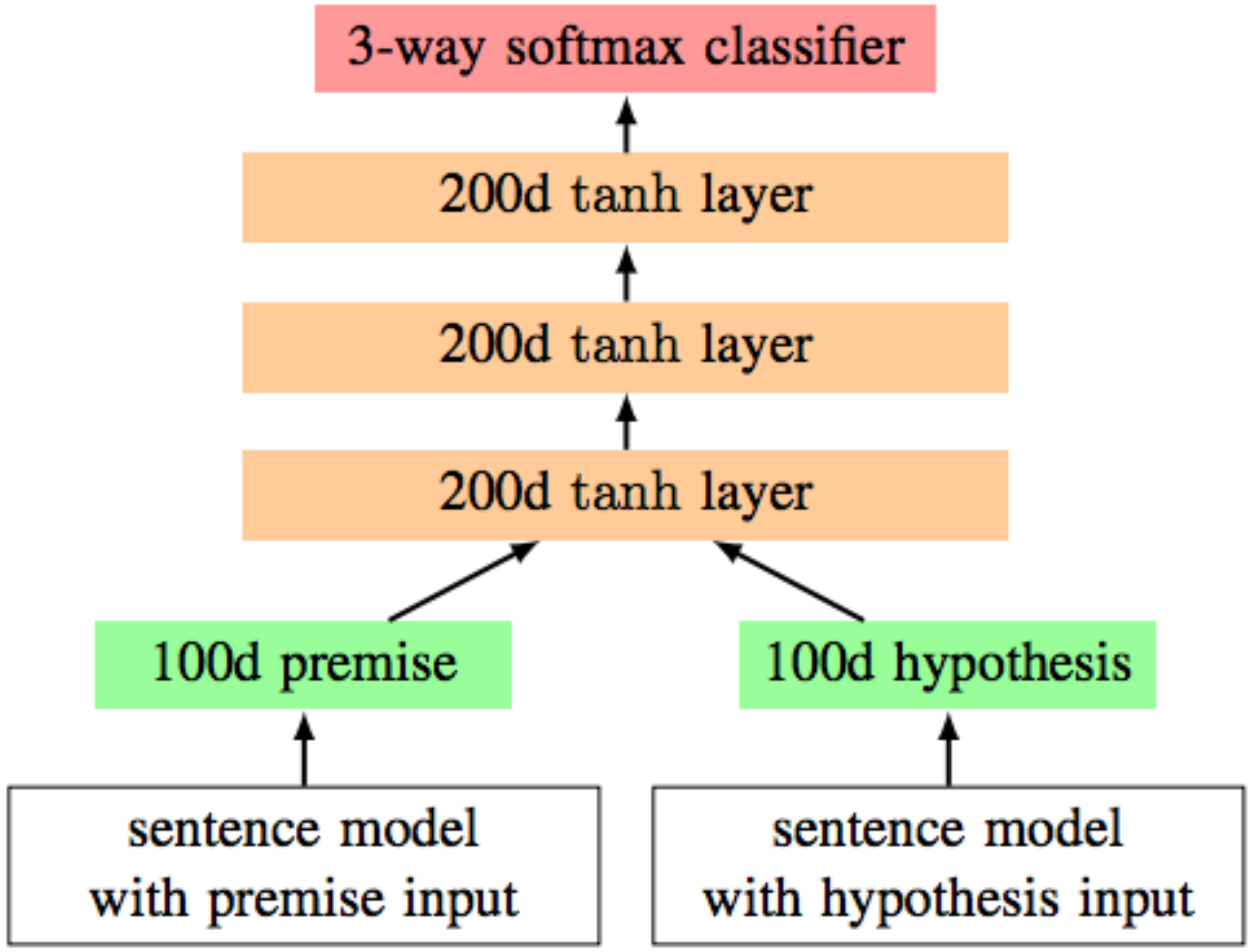
- Later: better models for this



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This Lecture

- CNNs

- CNNs for Sentiment

- Neural CRFs

CNNs

Convolutional Layer

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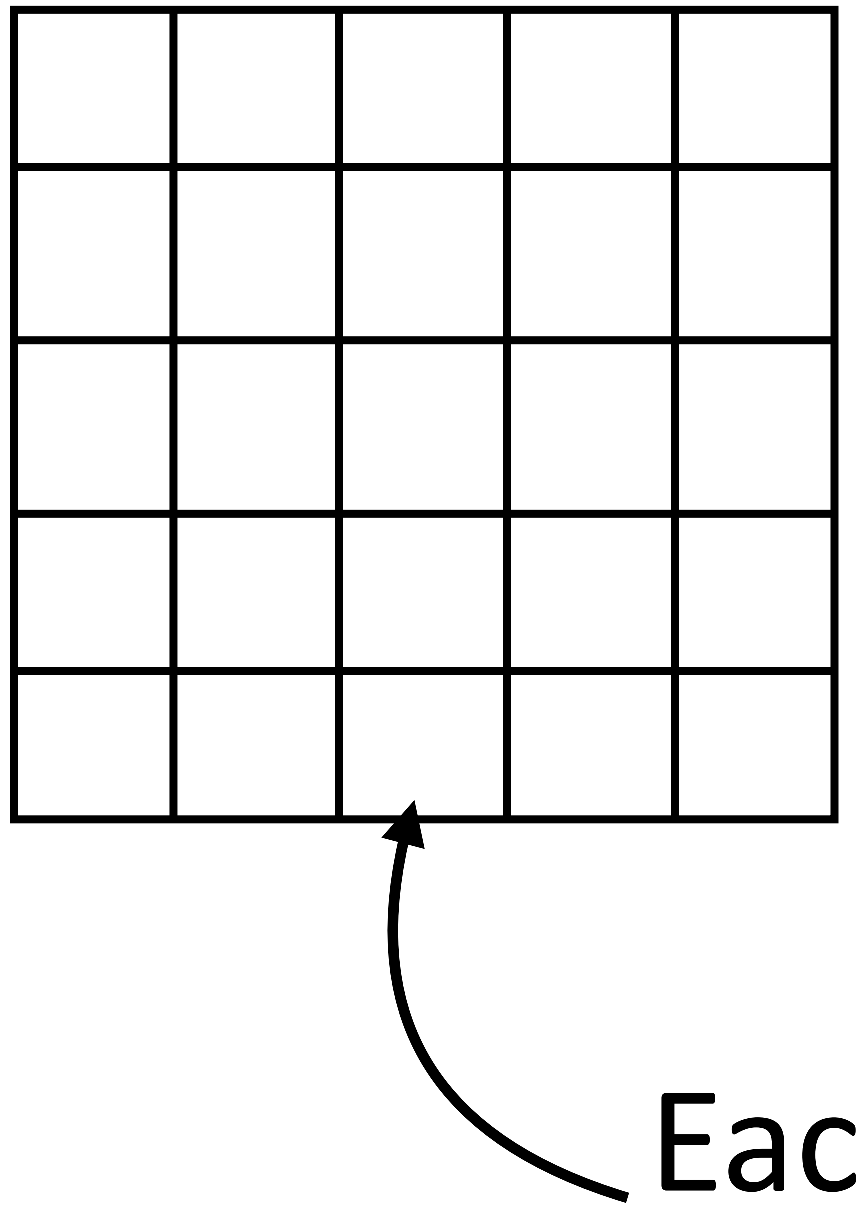

Each of these cells is a vector with multiple values

Images: RGB values (3 dim)

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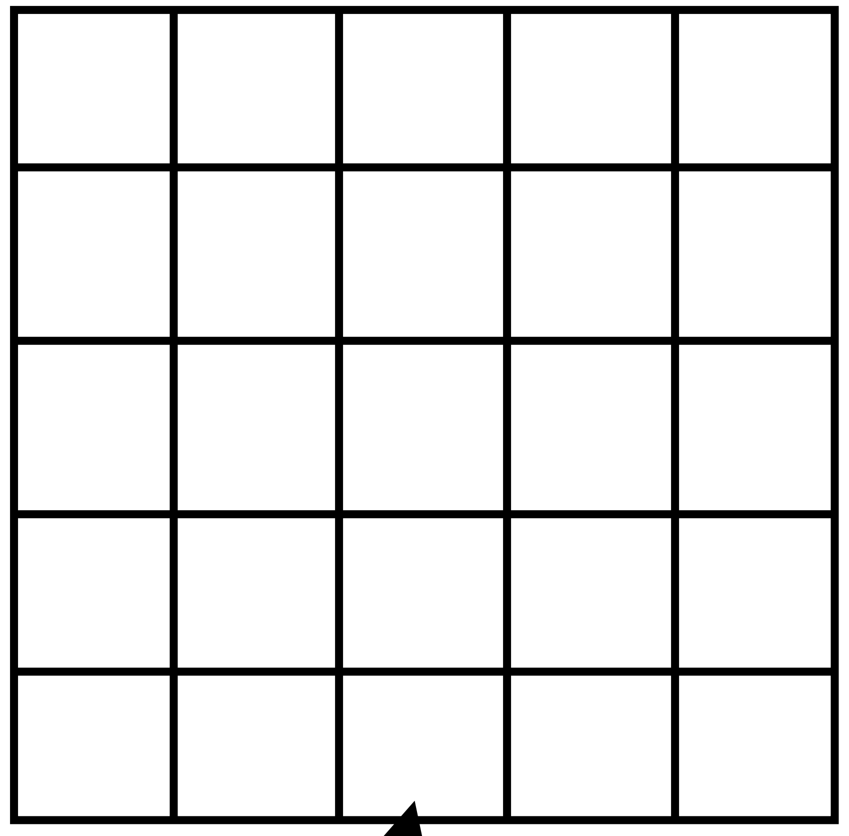

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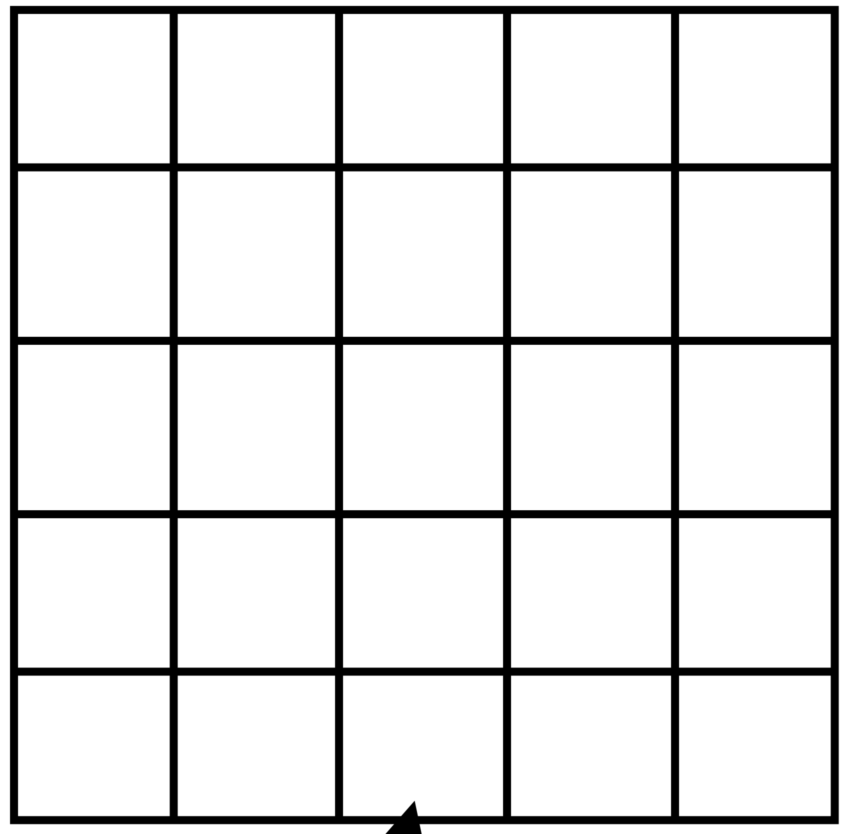

filter: m x m x k

sum over dot products

$$\text{activation}_{ij} = \sum_{i_o=0}^{k-1} \sum_{j_o=0}^{k-1} \text{image}(i + i_o, j + j_o) \cdot \text{filter}(i_o, j_o)$$

offsets

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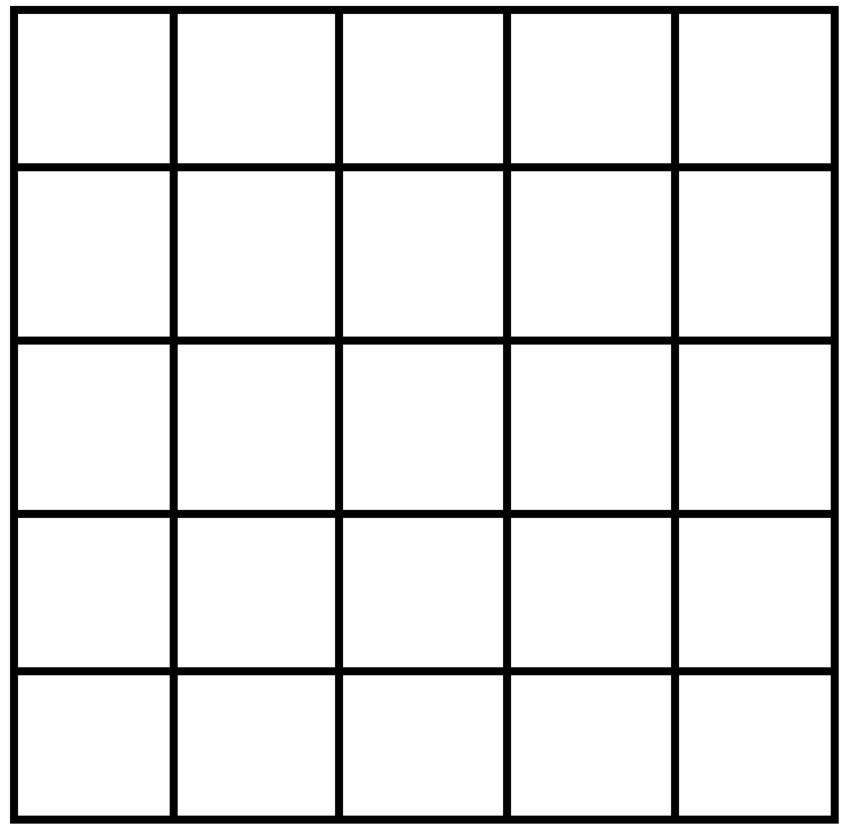

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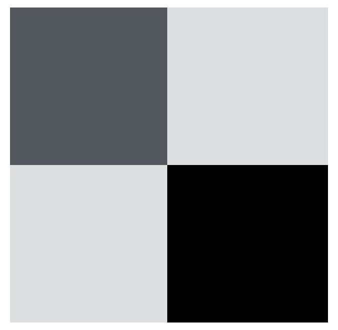

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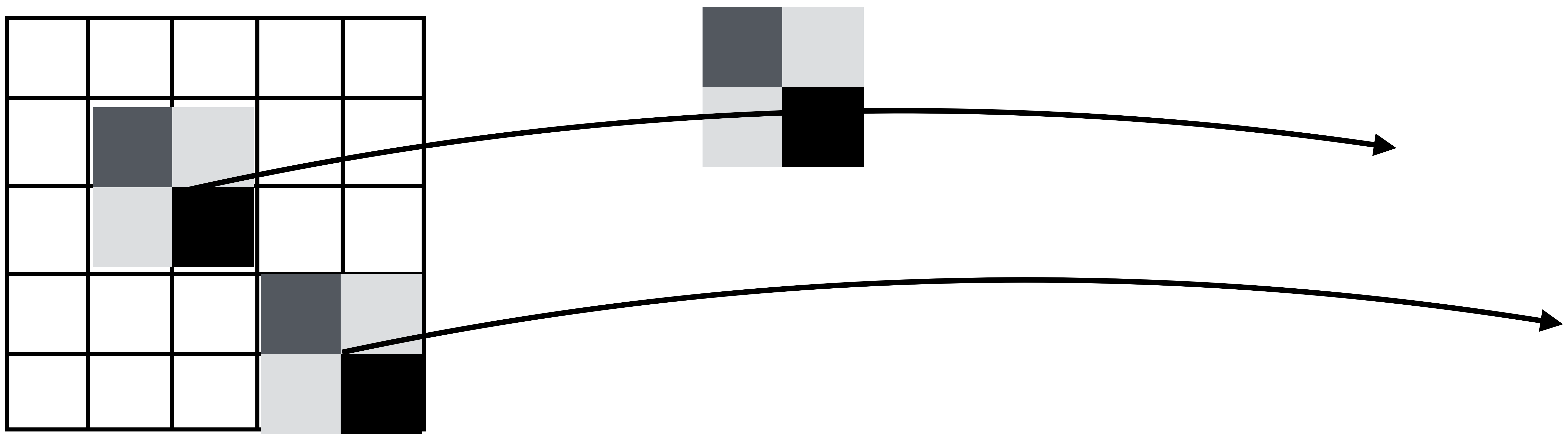

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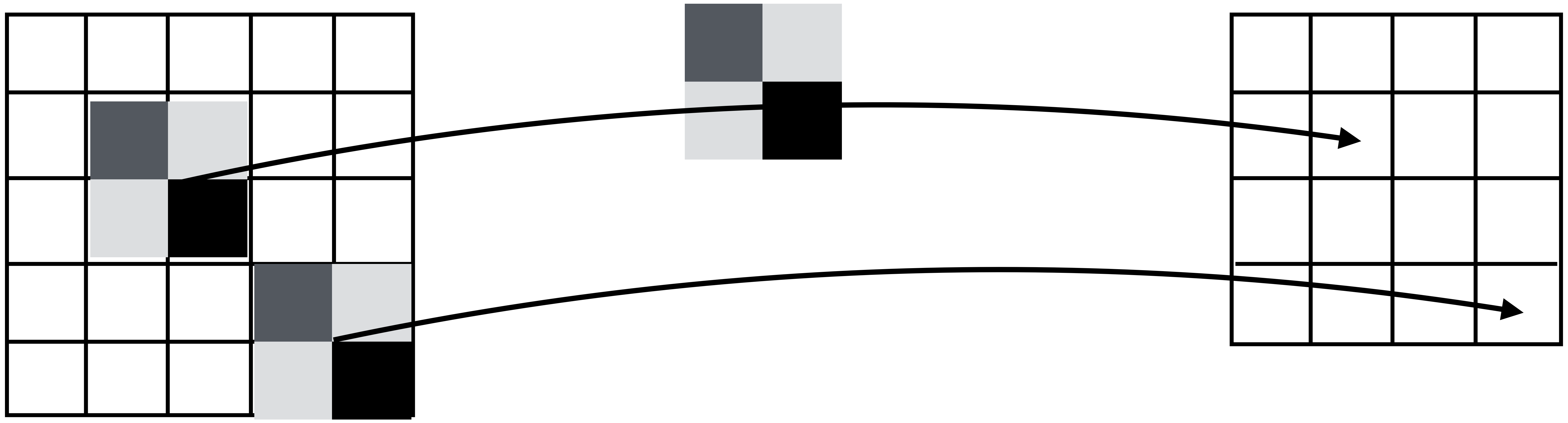
image: n x n x k   filter: m x m x k   activations: (n - m + 1) x (n - m + 1) x 1



Convolutions for NLP

- Input and filter are 2-dimensional instead of 3-dimensional

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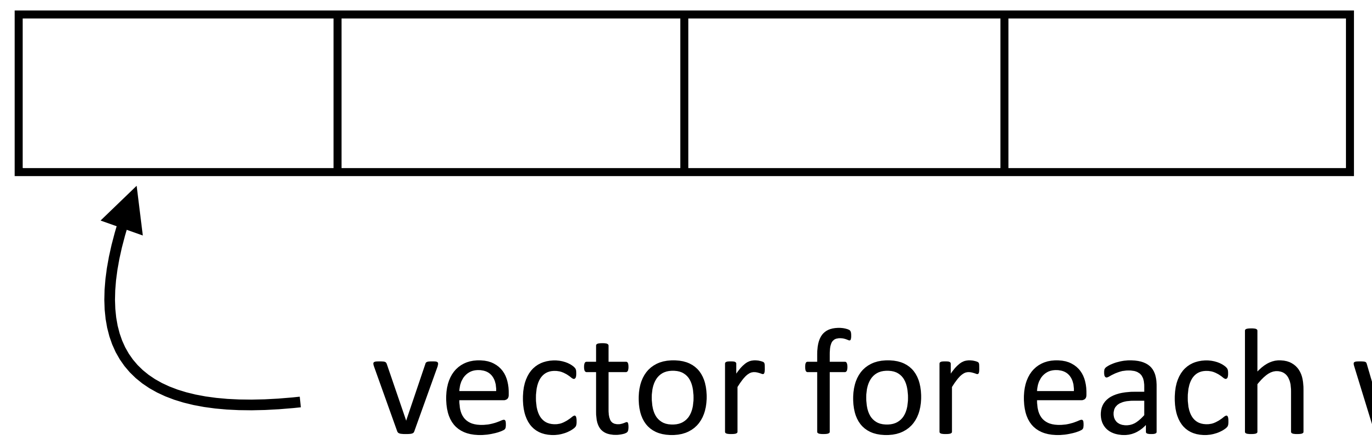
sentence: n words x k vec dim

the movie was good



vector for each word

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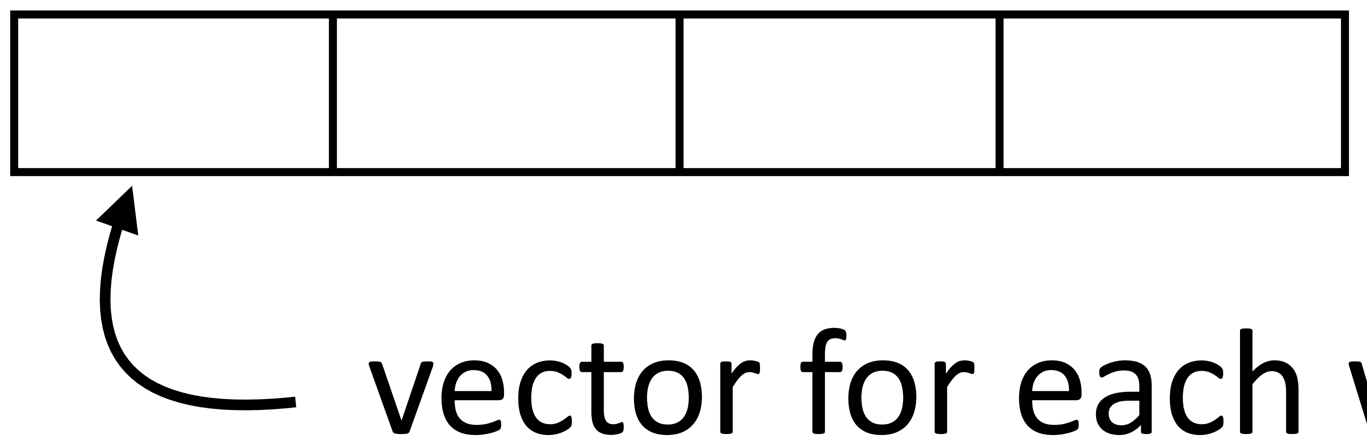

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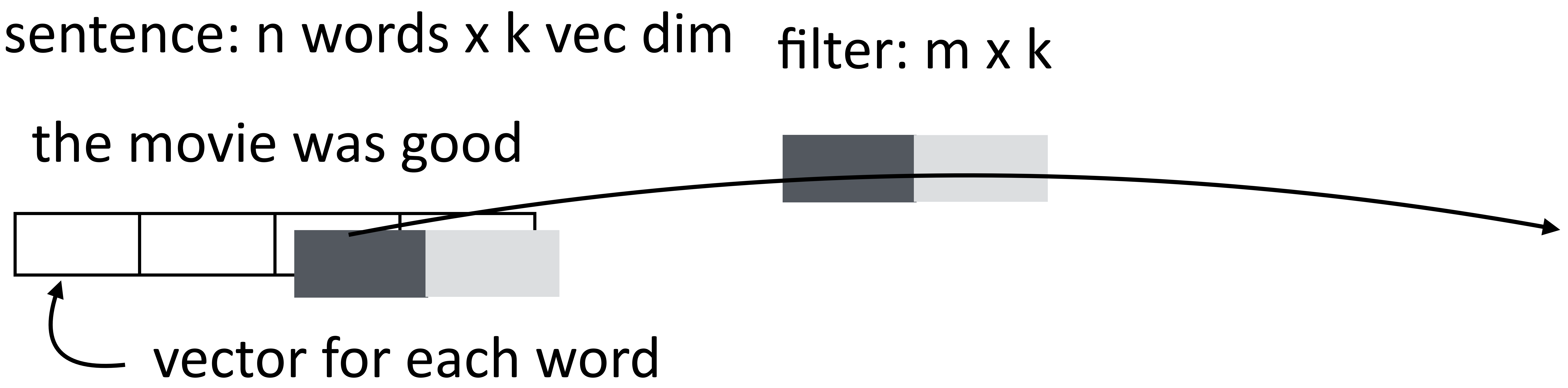

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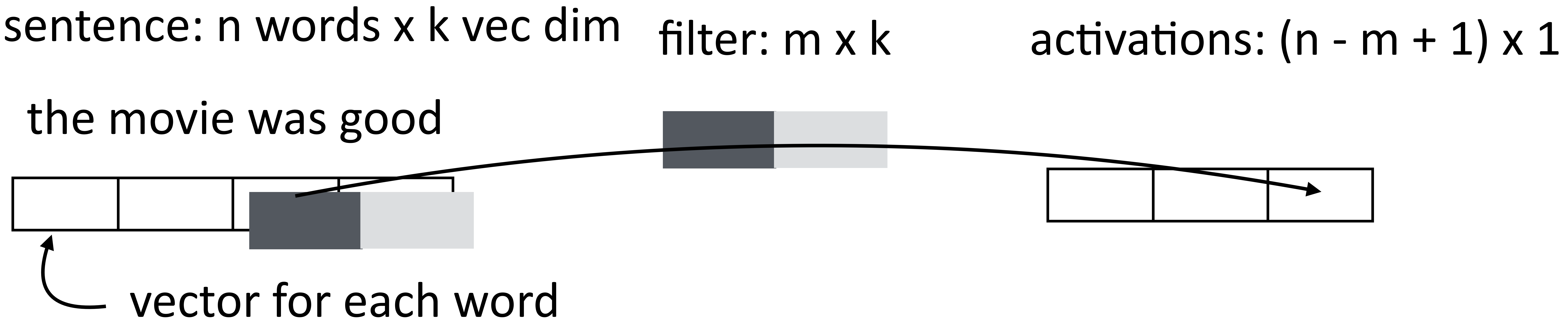

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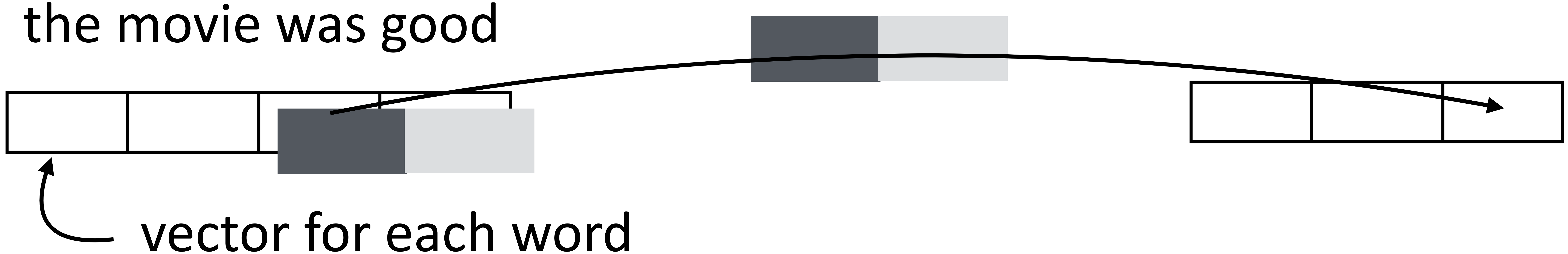
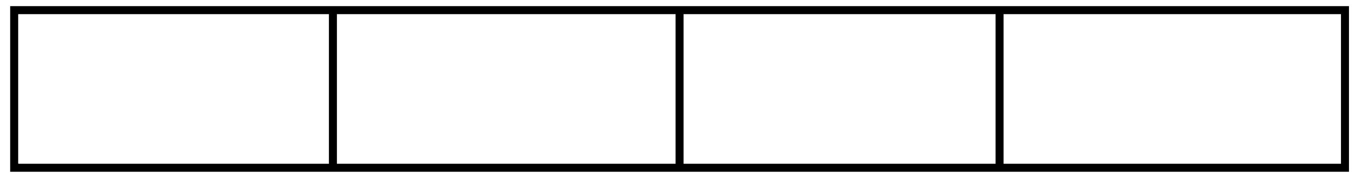


vector for each word

- Combines evidence locally in a sentence and produces a new (but still variable-length) representation

Compare: CNNs vs. LSTMs



n x k

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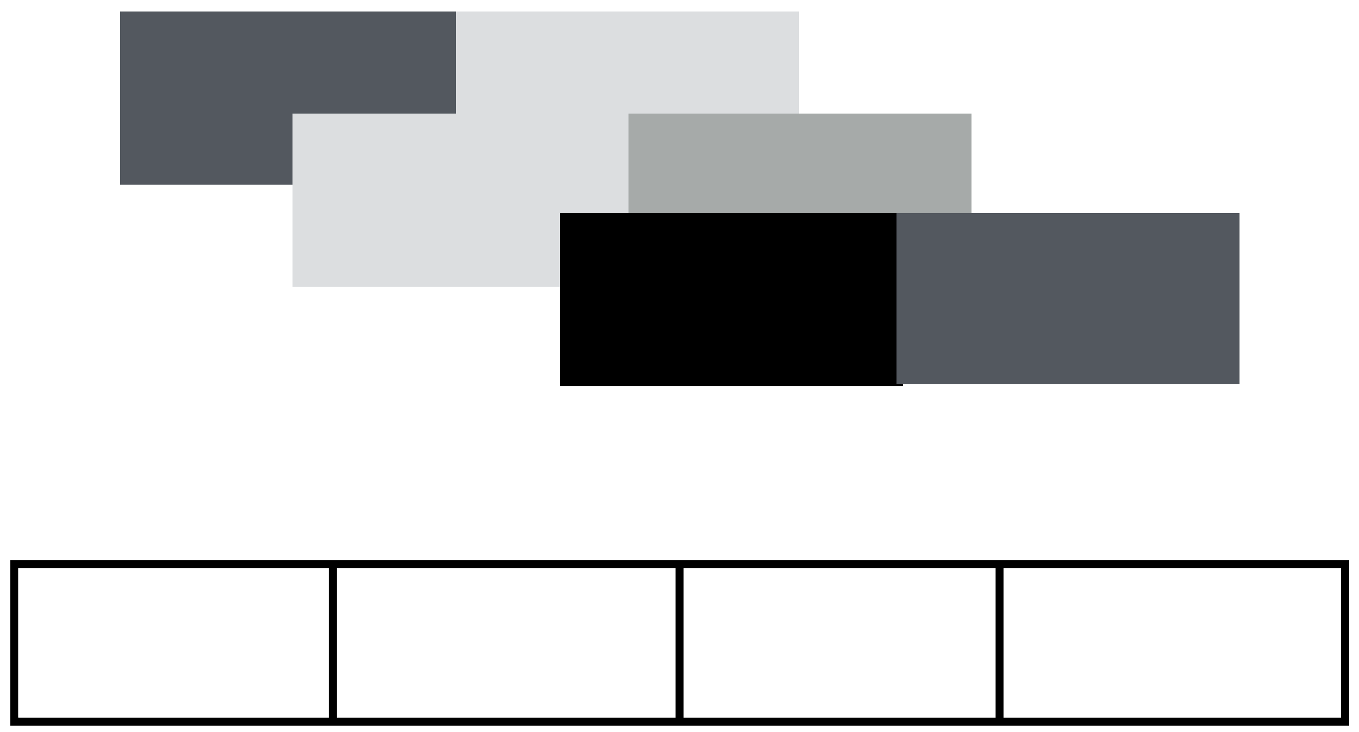

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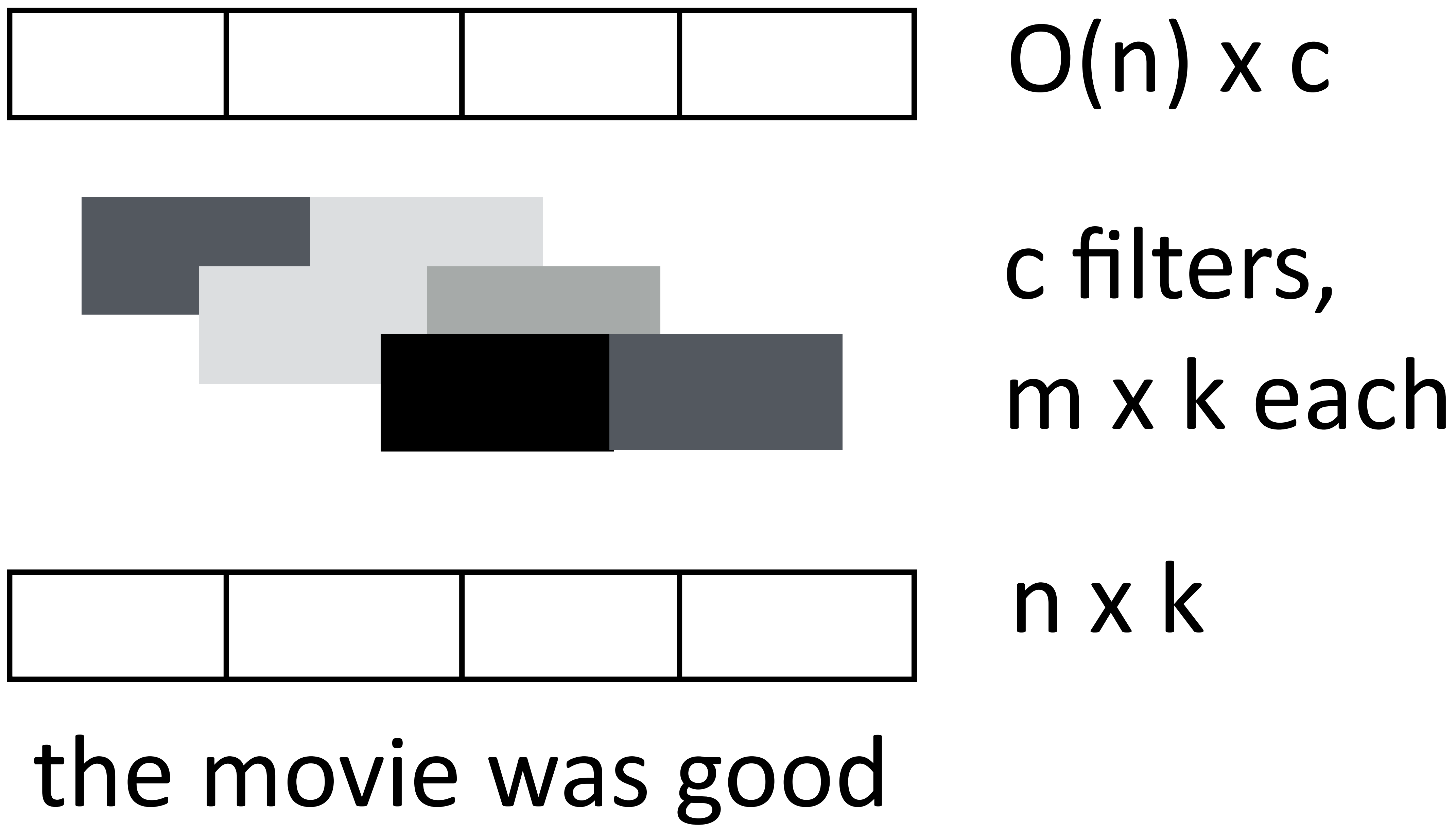

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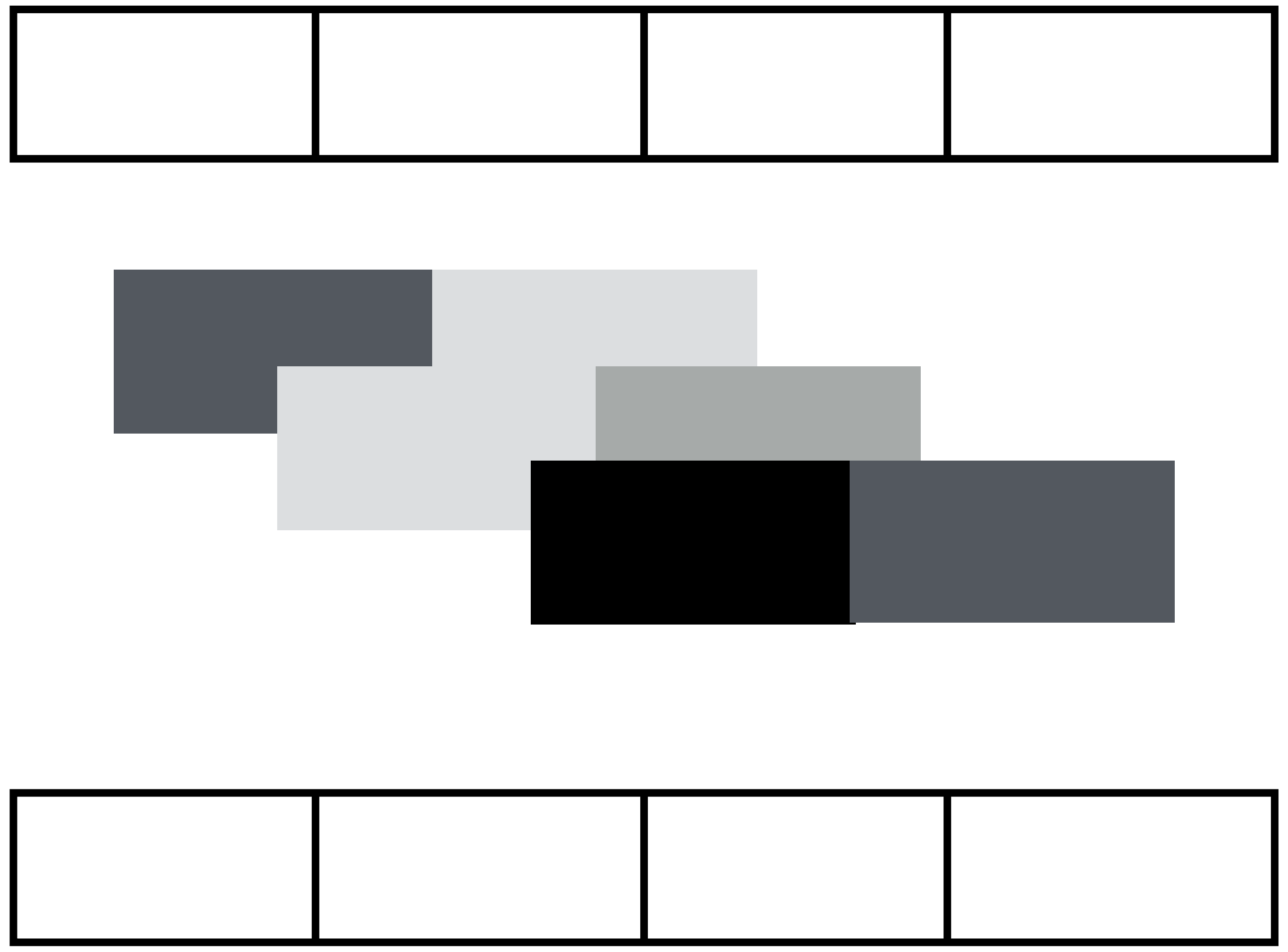

O(n) x c

c filters,
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n x k

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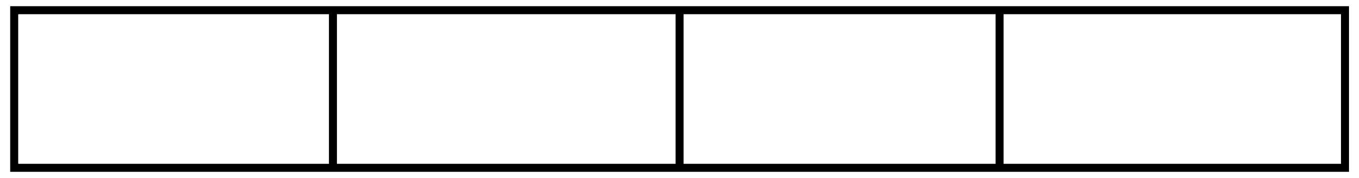

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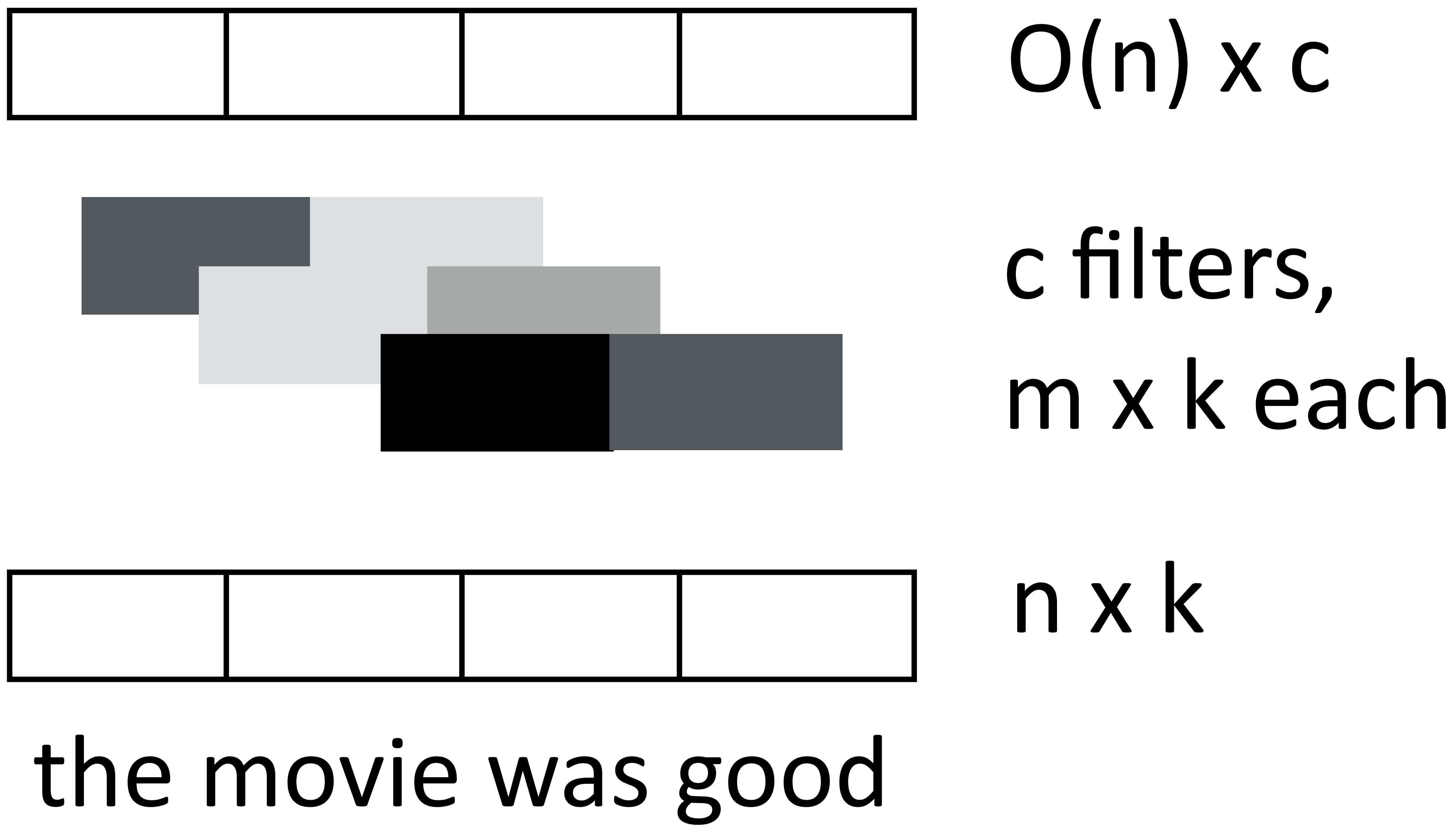

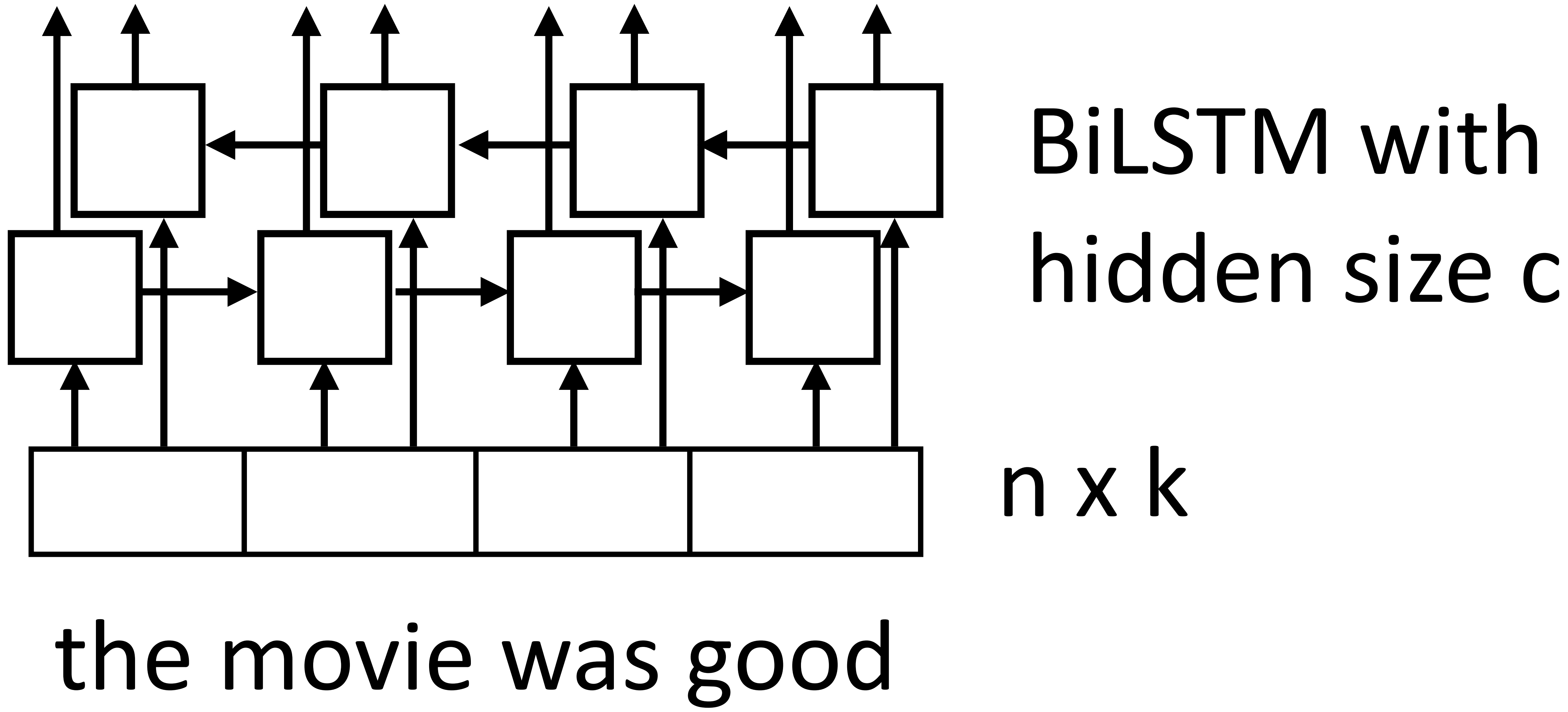

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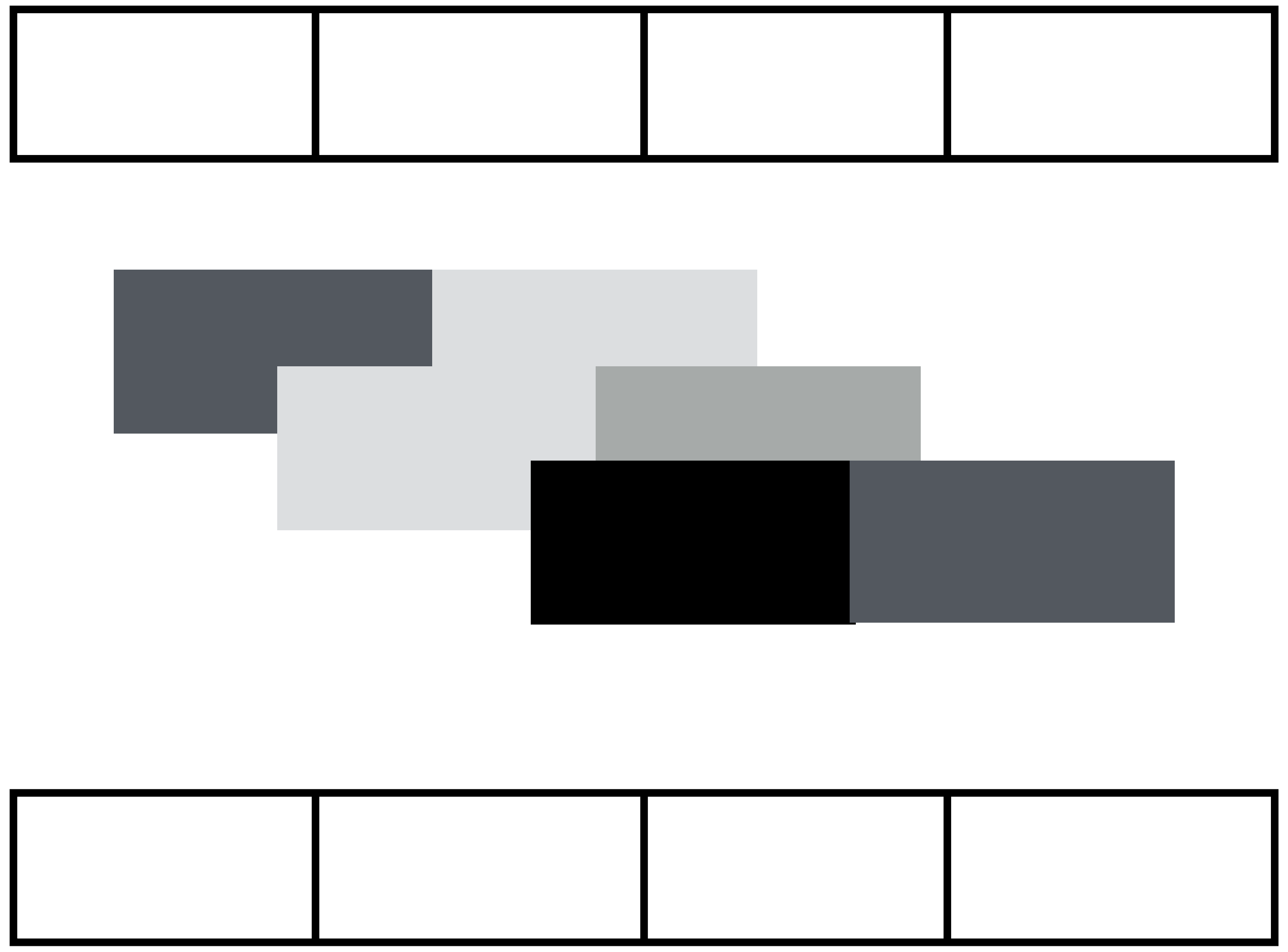

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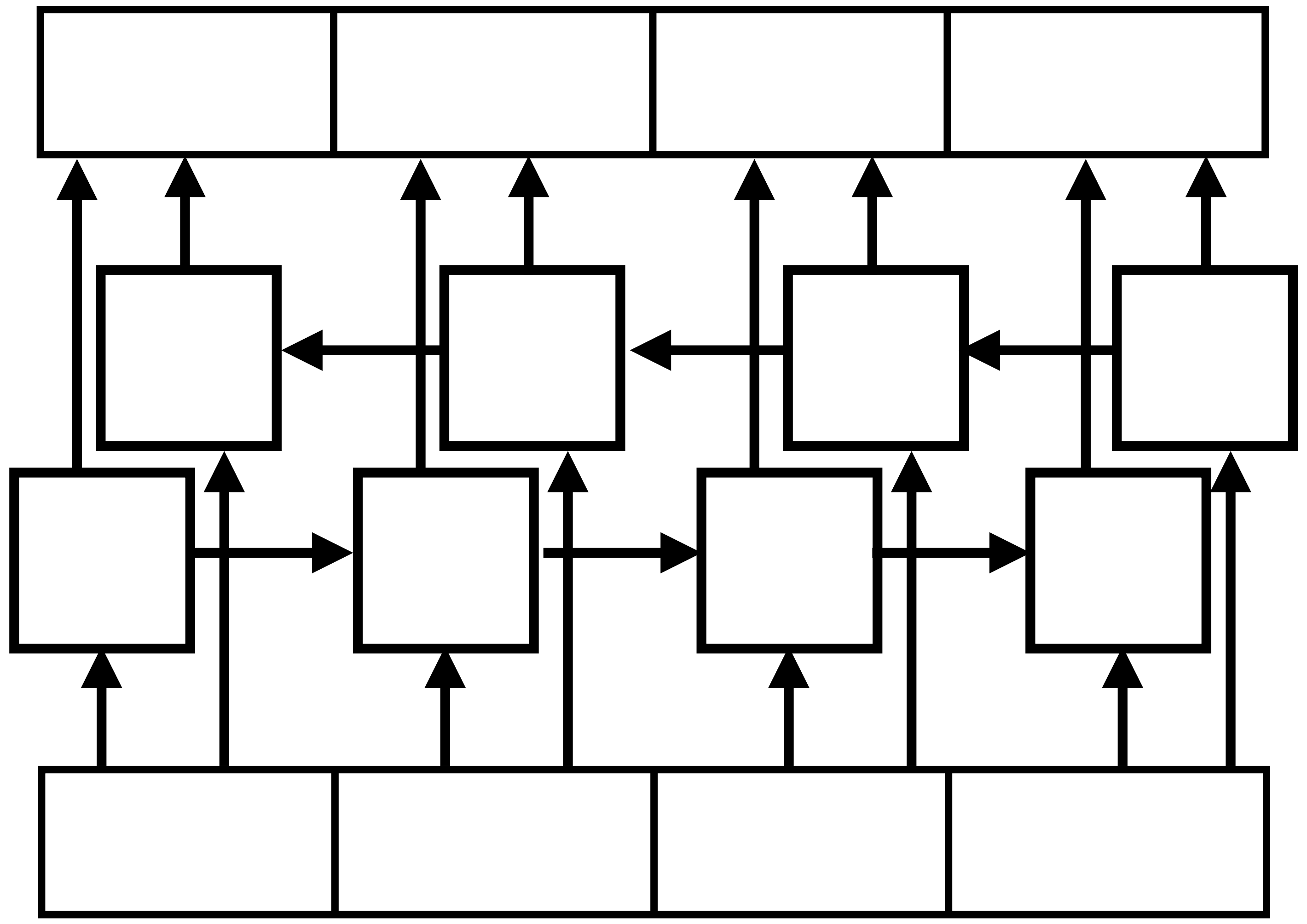

BiLSTM with
hidden size c

n x k

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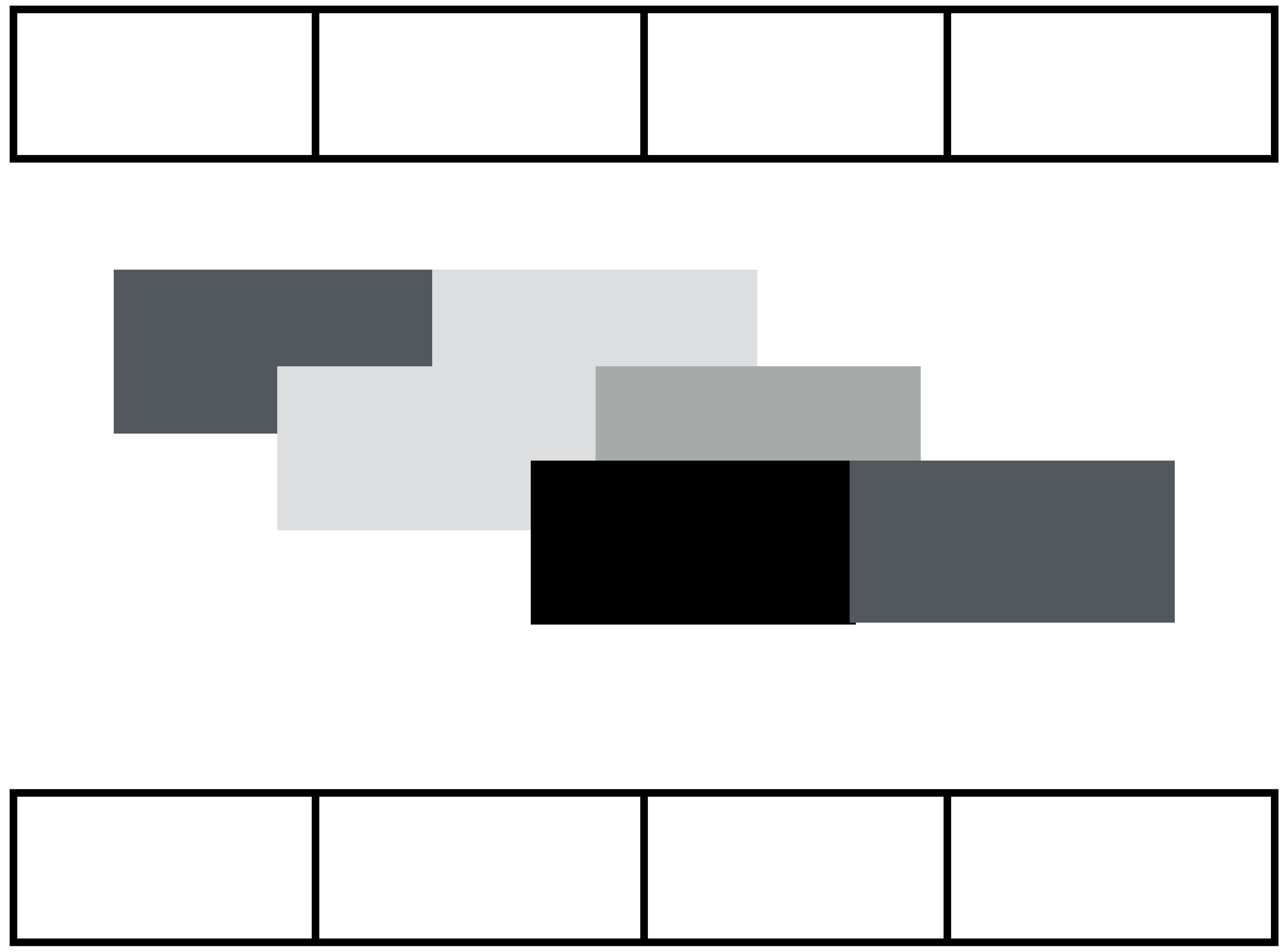
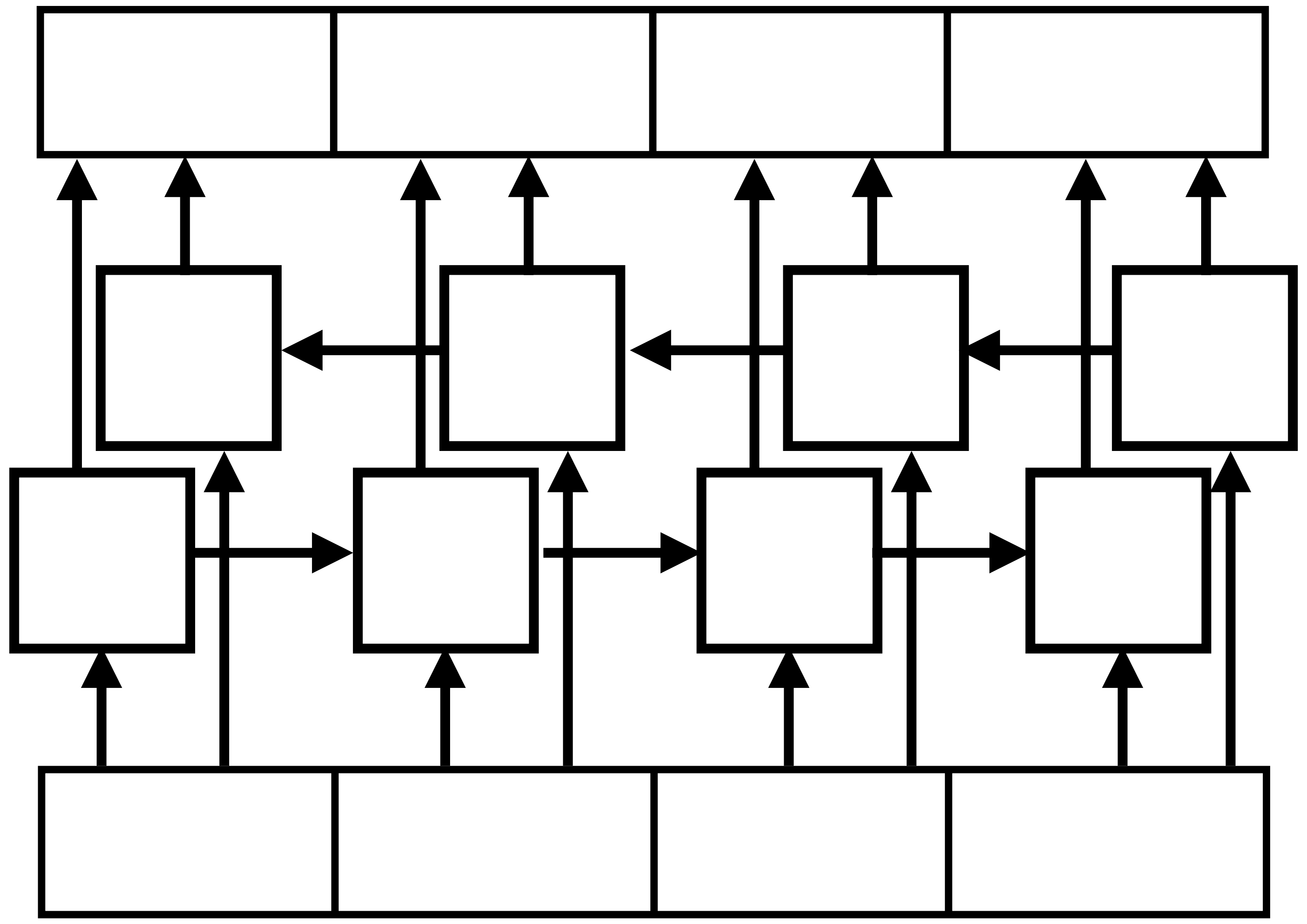
Compare: CNNs vs. LSTMs





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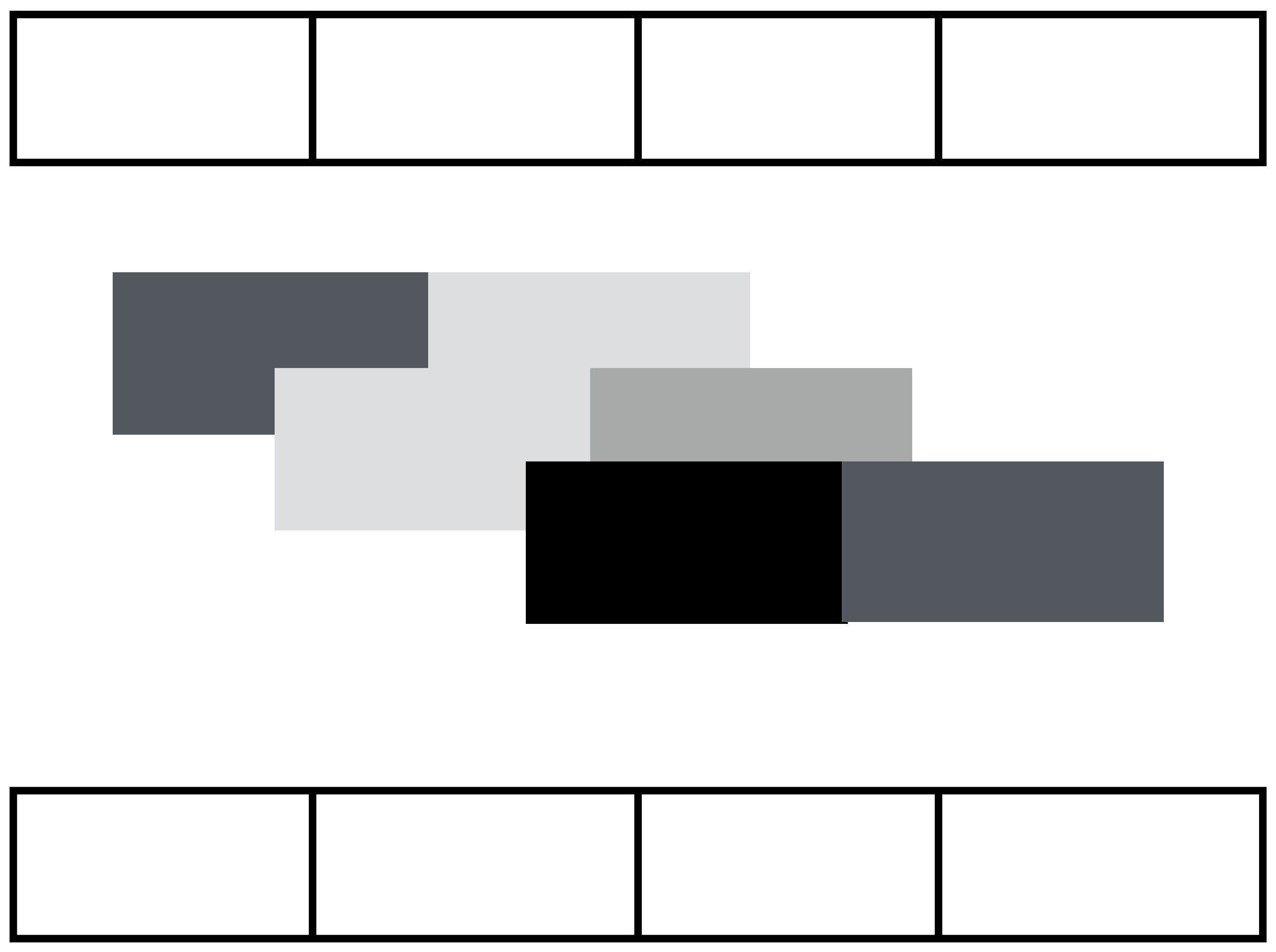

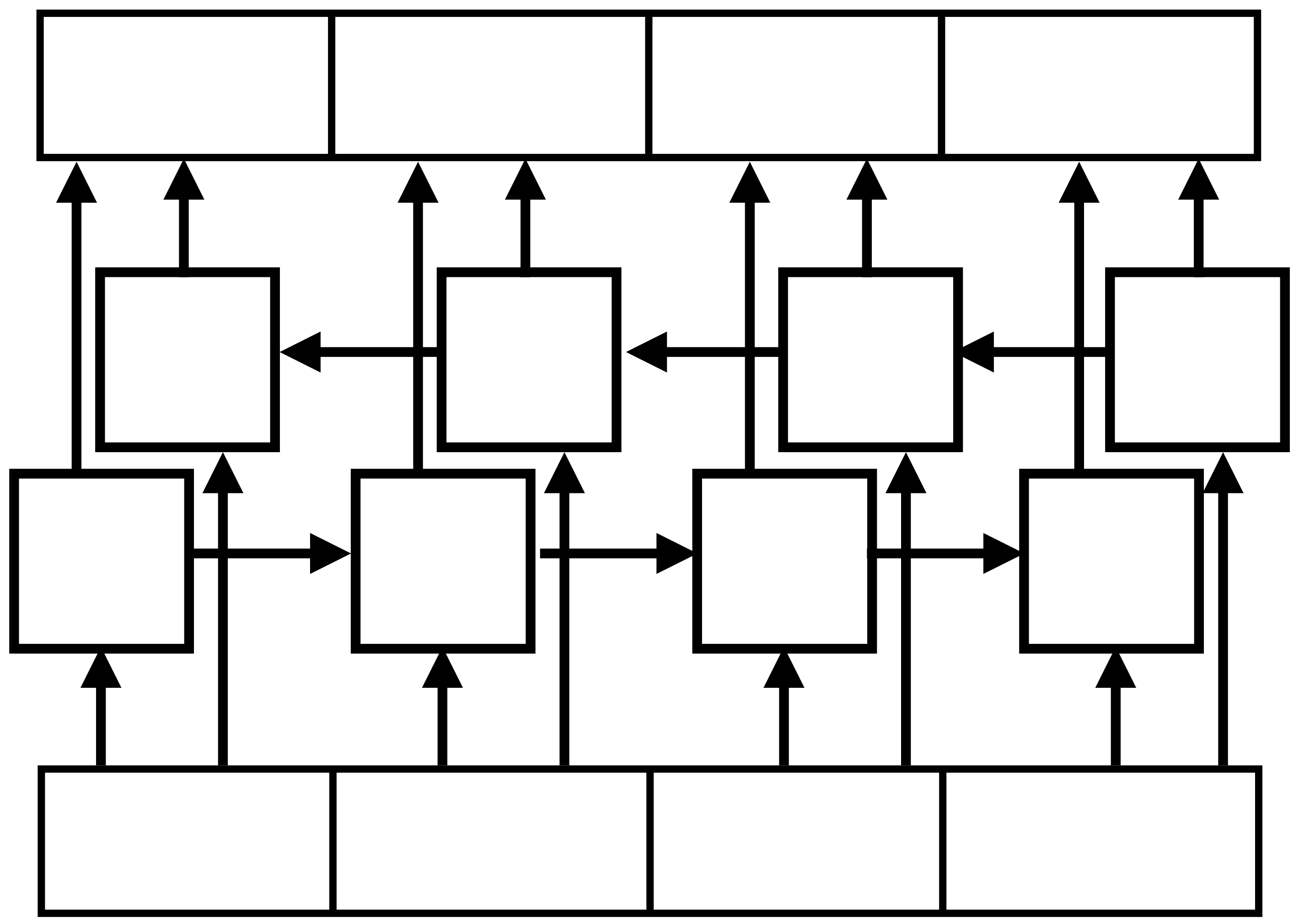

- Both LSTMs and convolutional layers transform the input using context

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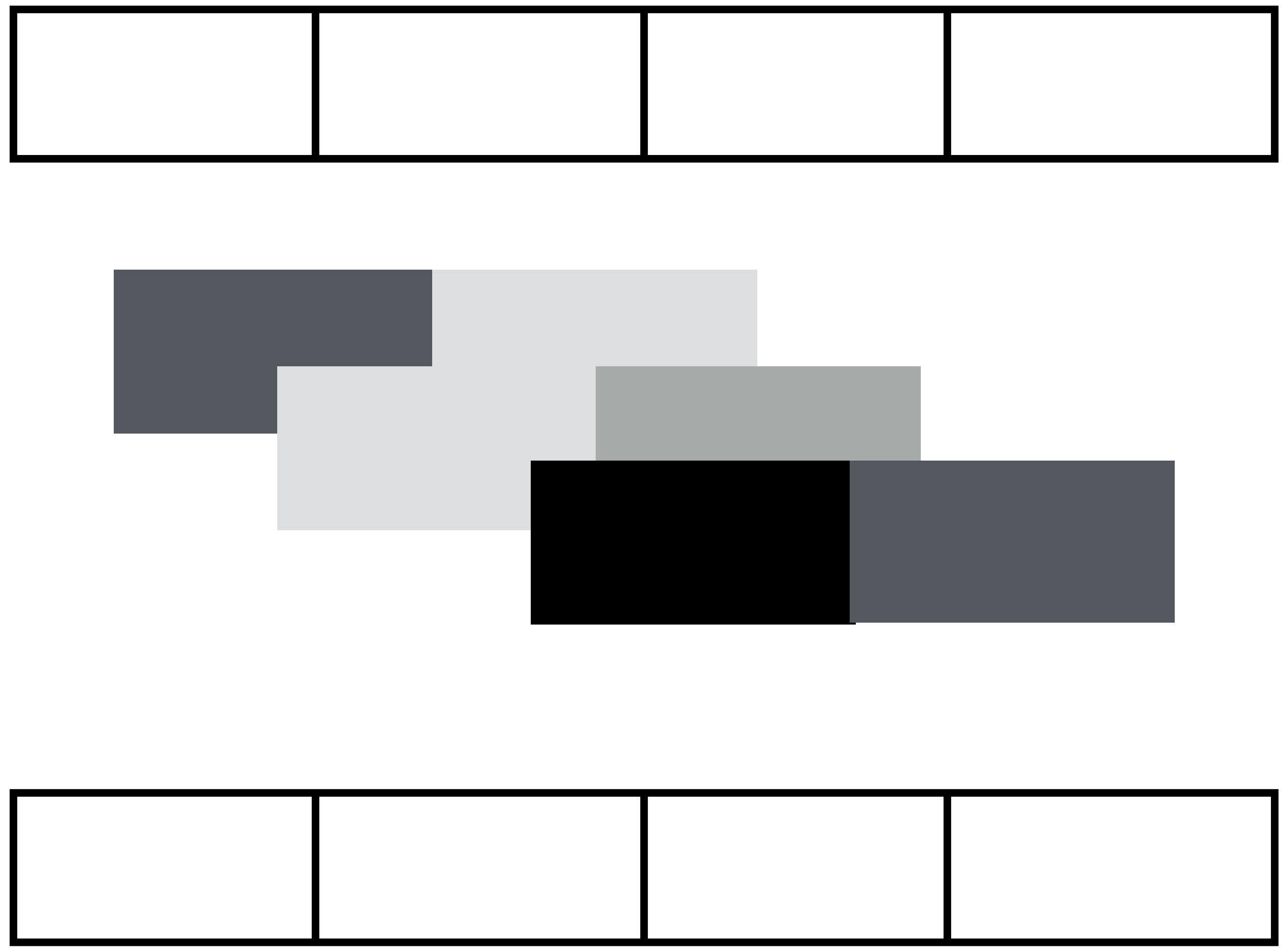

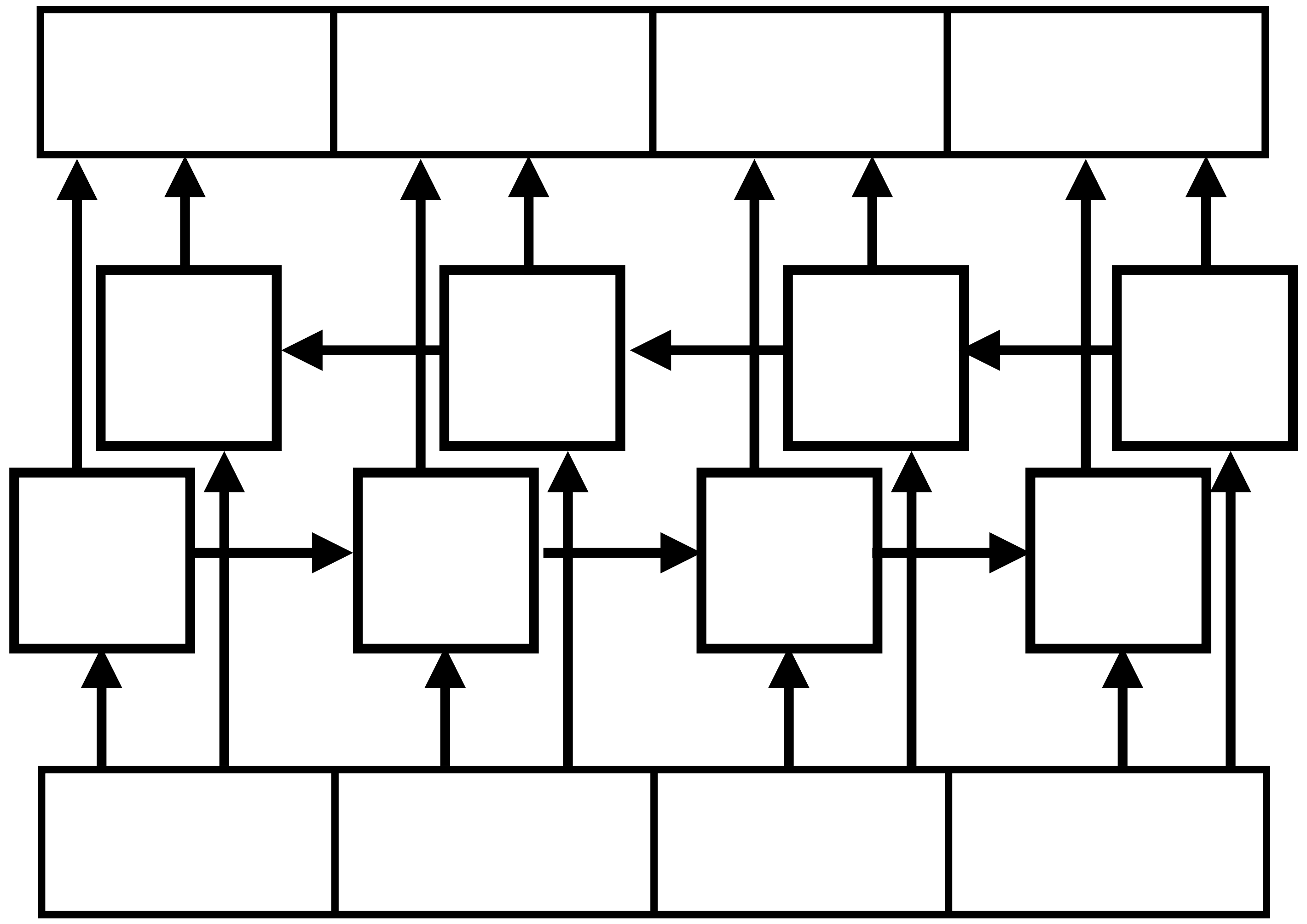

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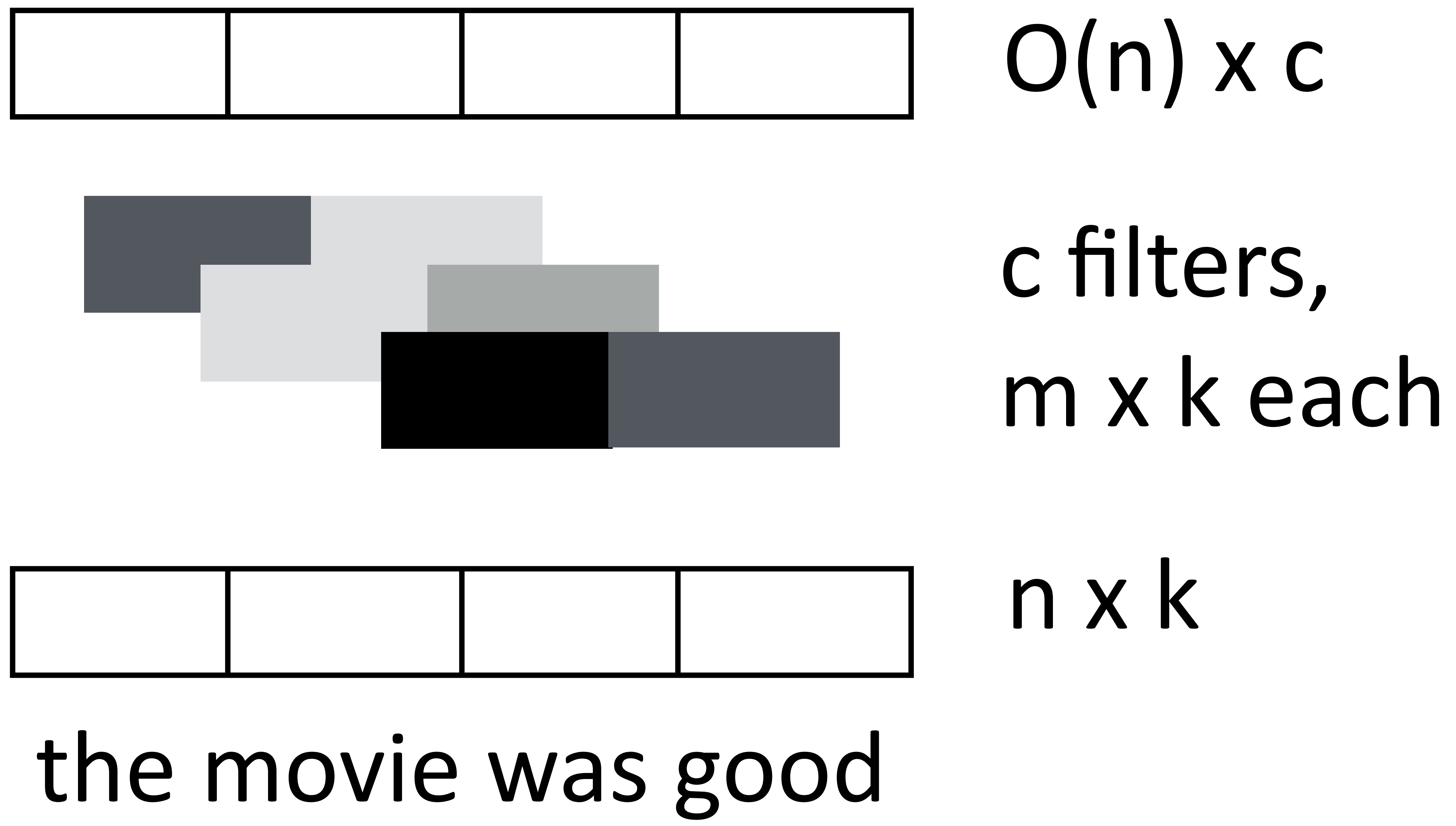

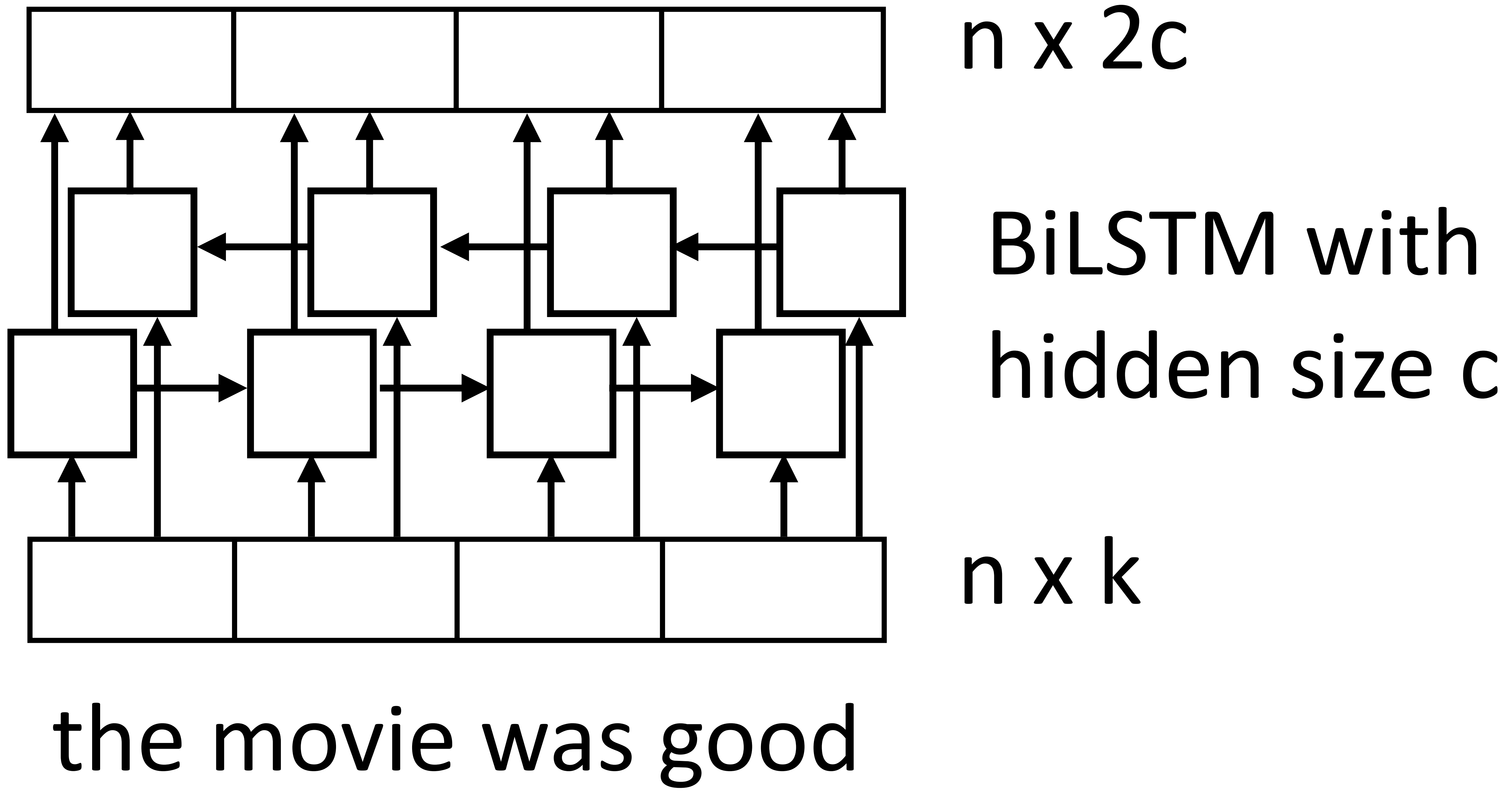

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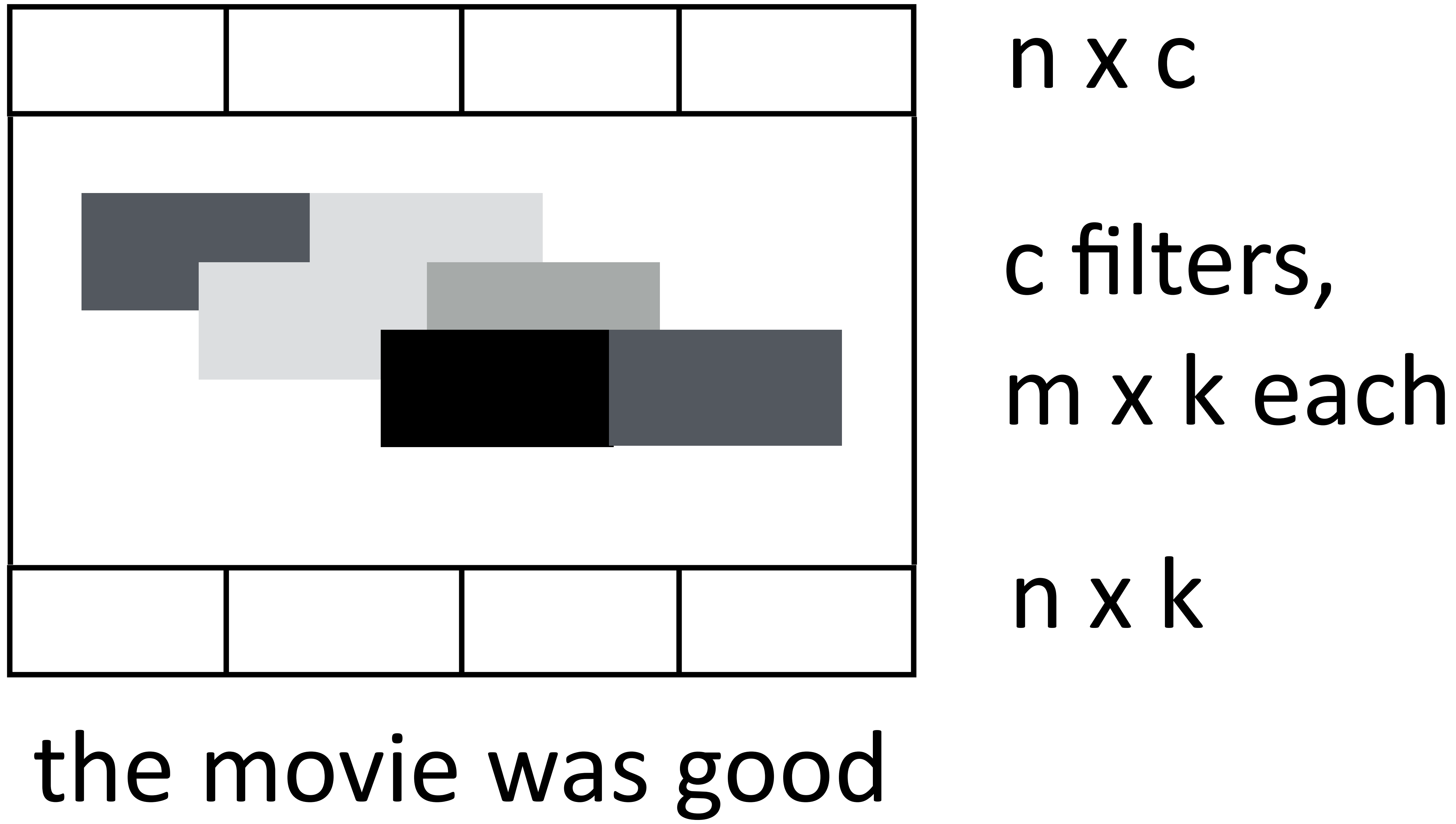
- CNN: local depending on filter width + number of layers

CNNs for Sentiment

CNNs for Sentiment Analysis



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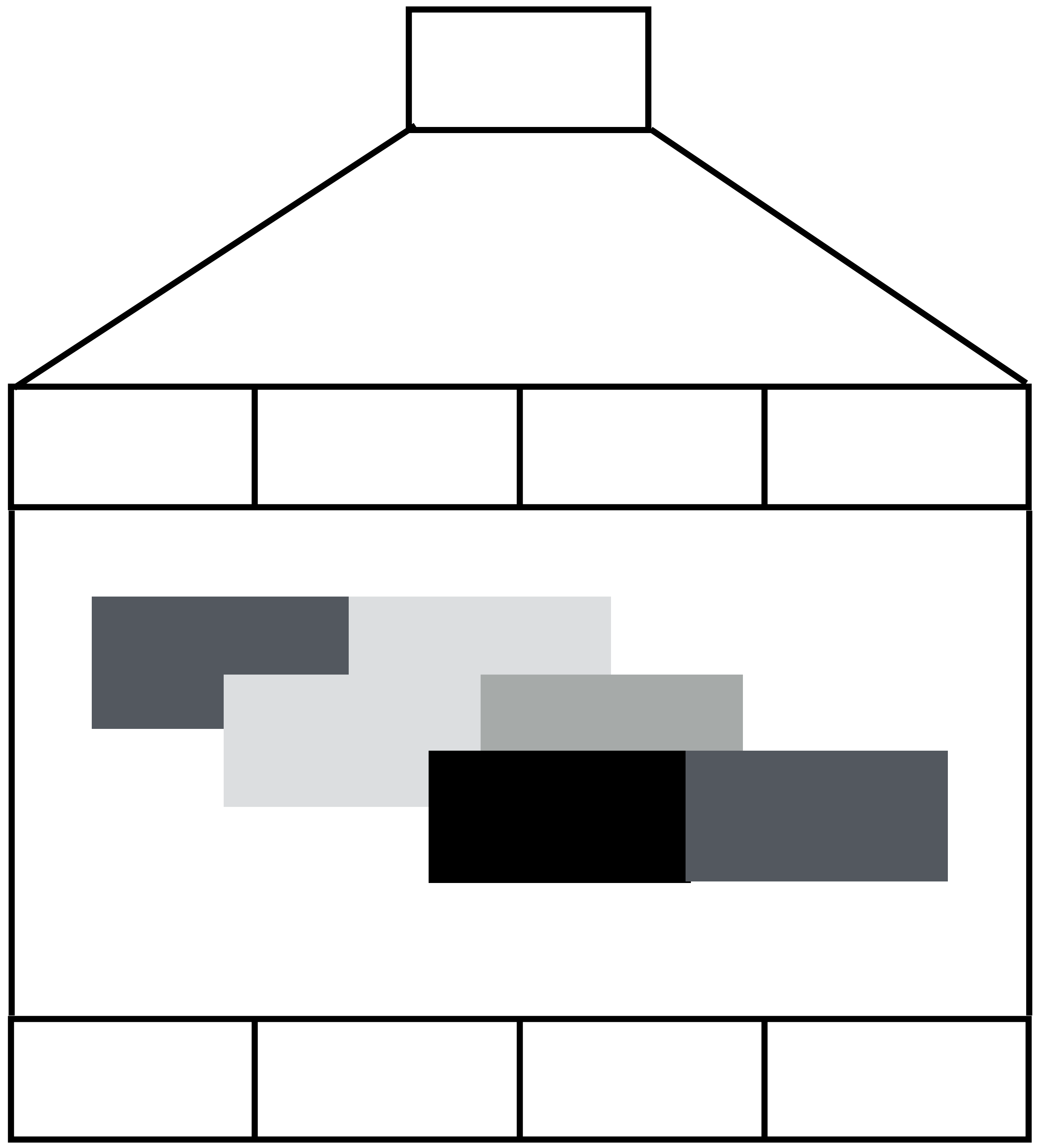


c-dimensional vector

max pooling over the sentence

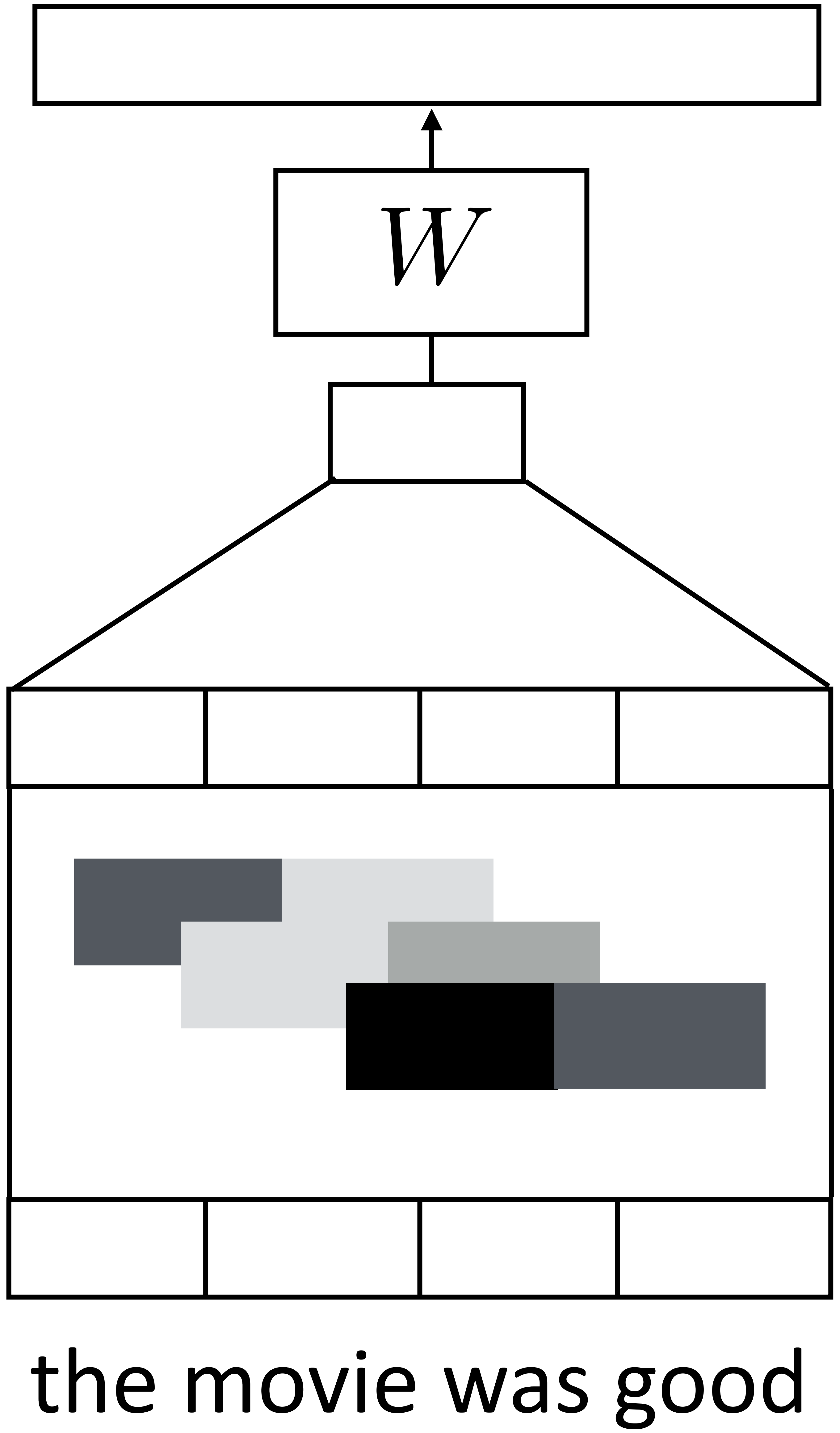
n x c

c filters,
m x k each

n x k

- Max pooling: return the max activation of a given filter over the entire sentence; like a logical OR (sum pooling is like logical AND)

CNNs for Sentiment Analysis



$P(y|\mathbf{x})$

projection + softmax

c-dimensional vector

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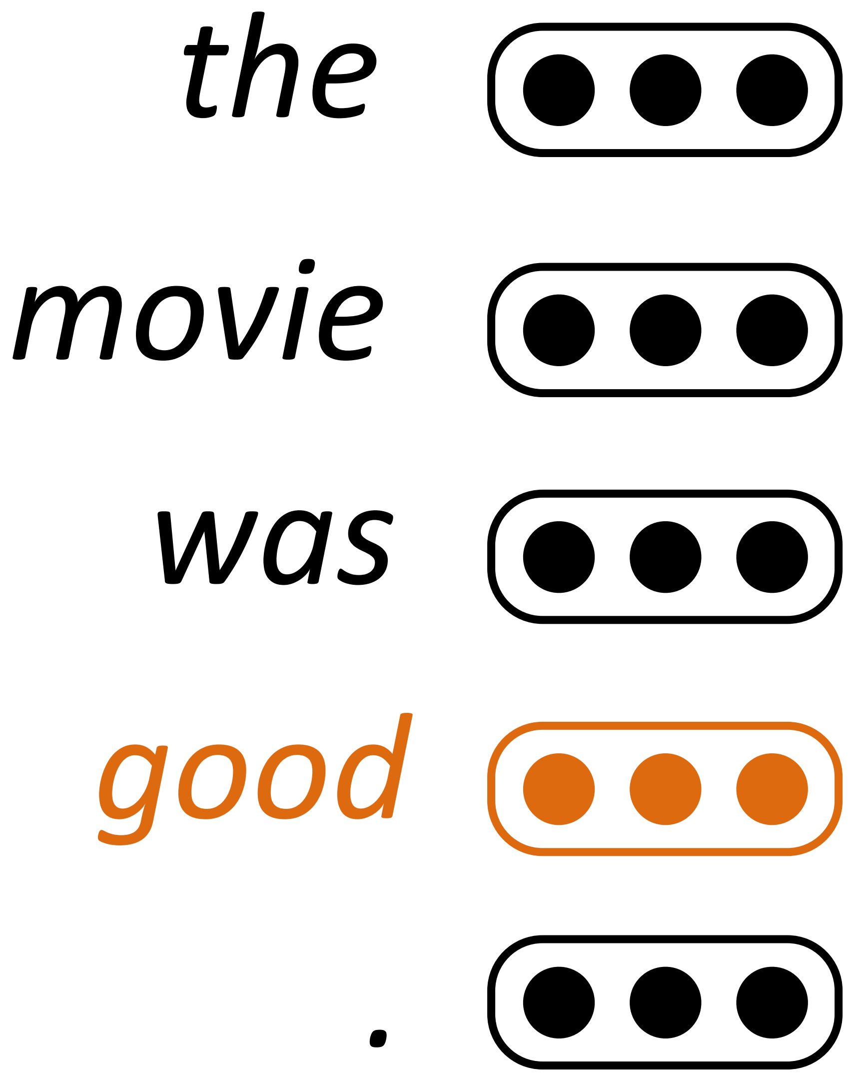
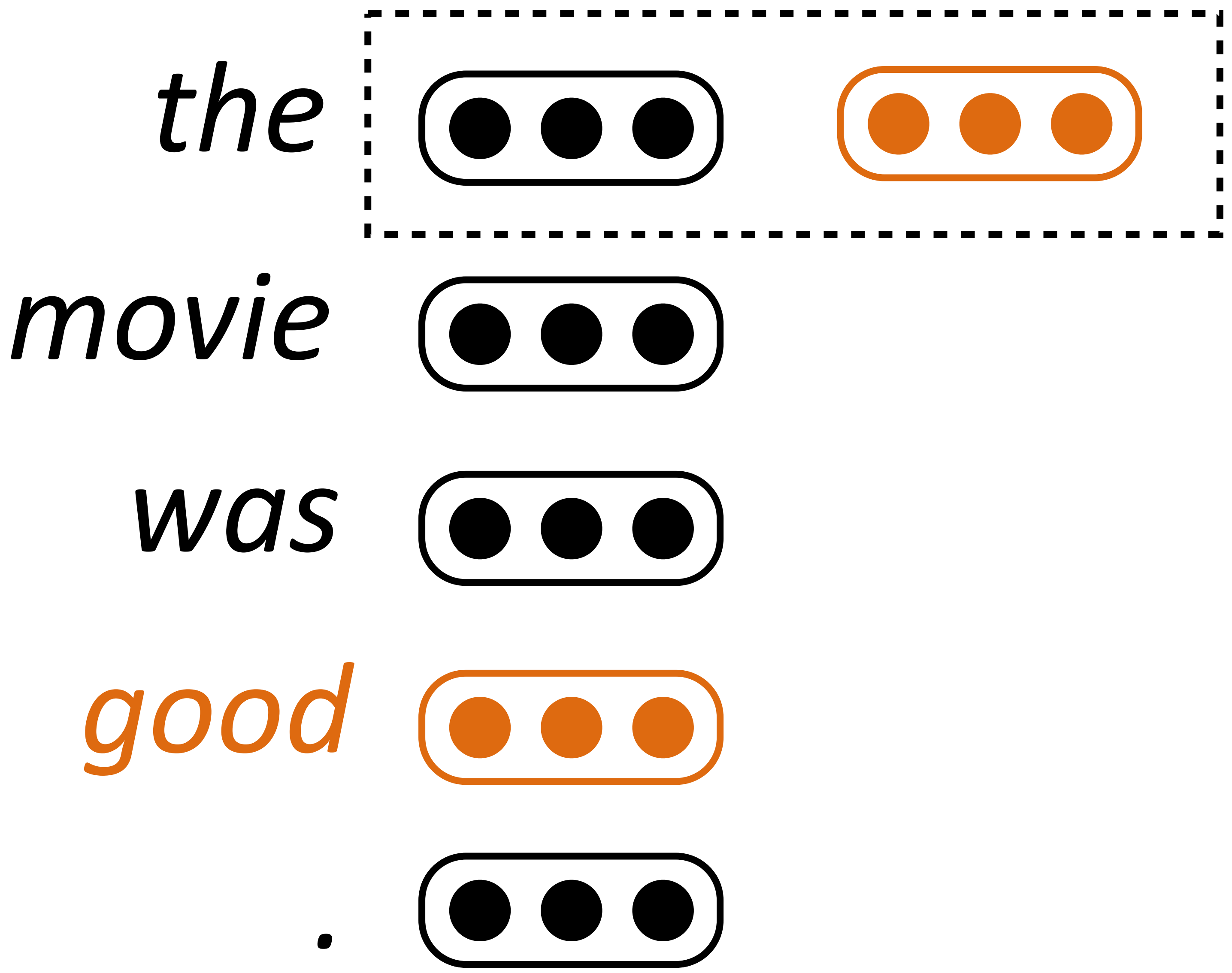
Understanding CNNs for Sentiment



- Filter "looks like" the things that will cause it to have high activation

Understanding CNNs for Sentiment



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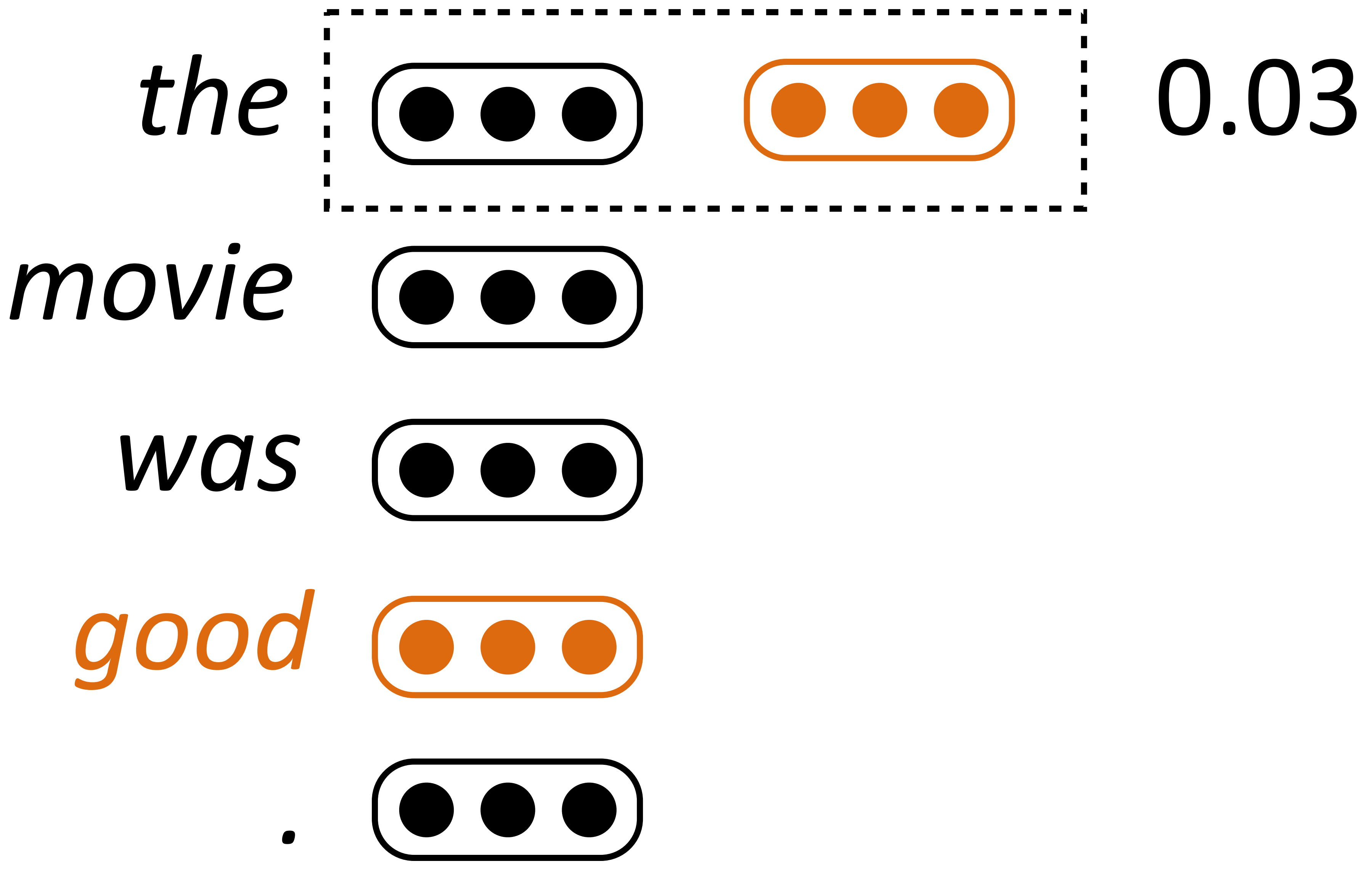

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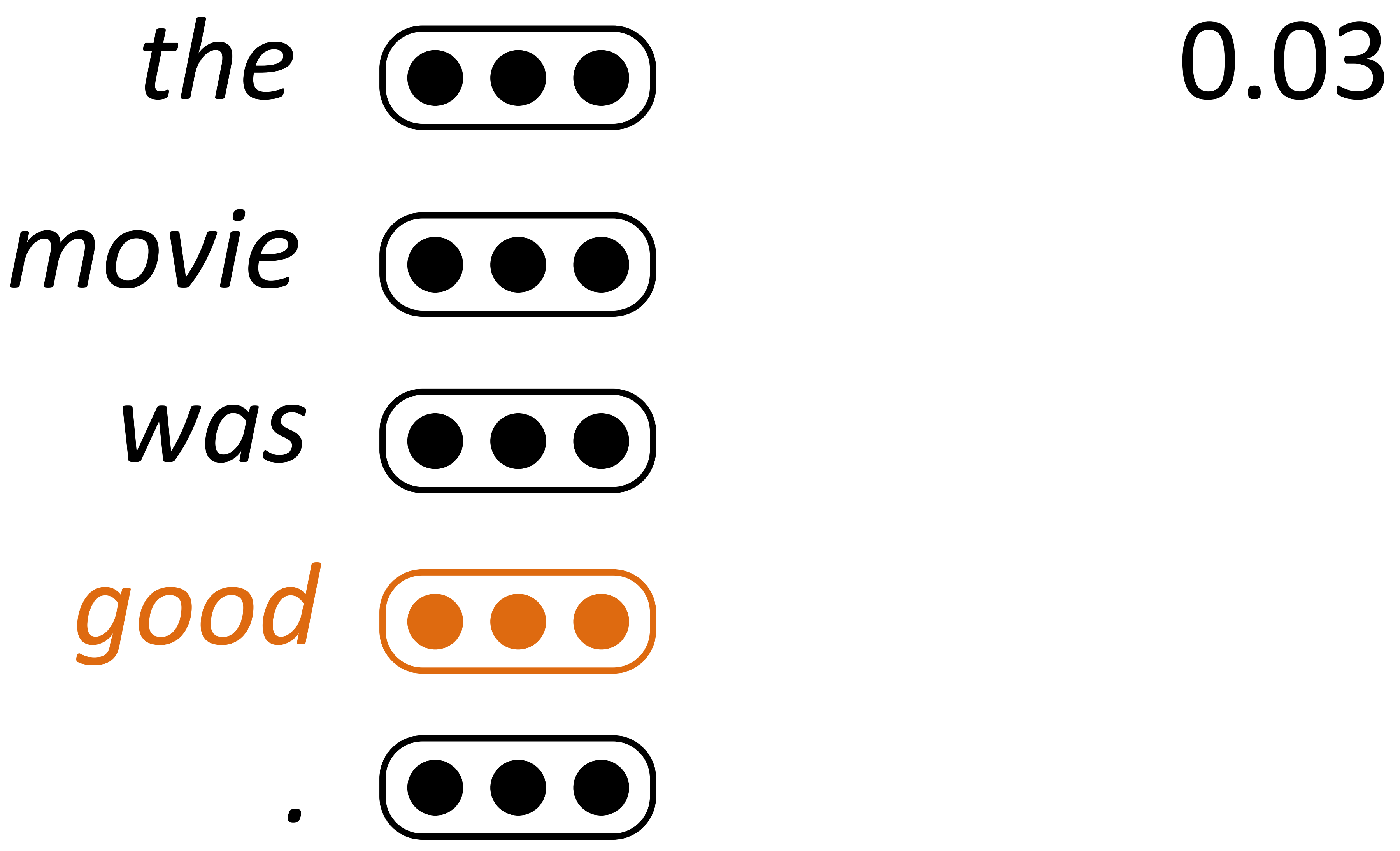

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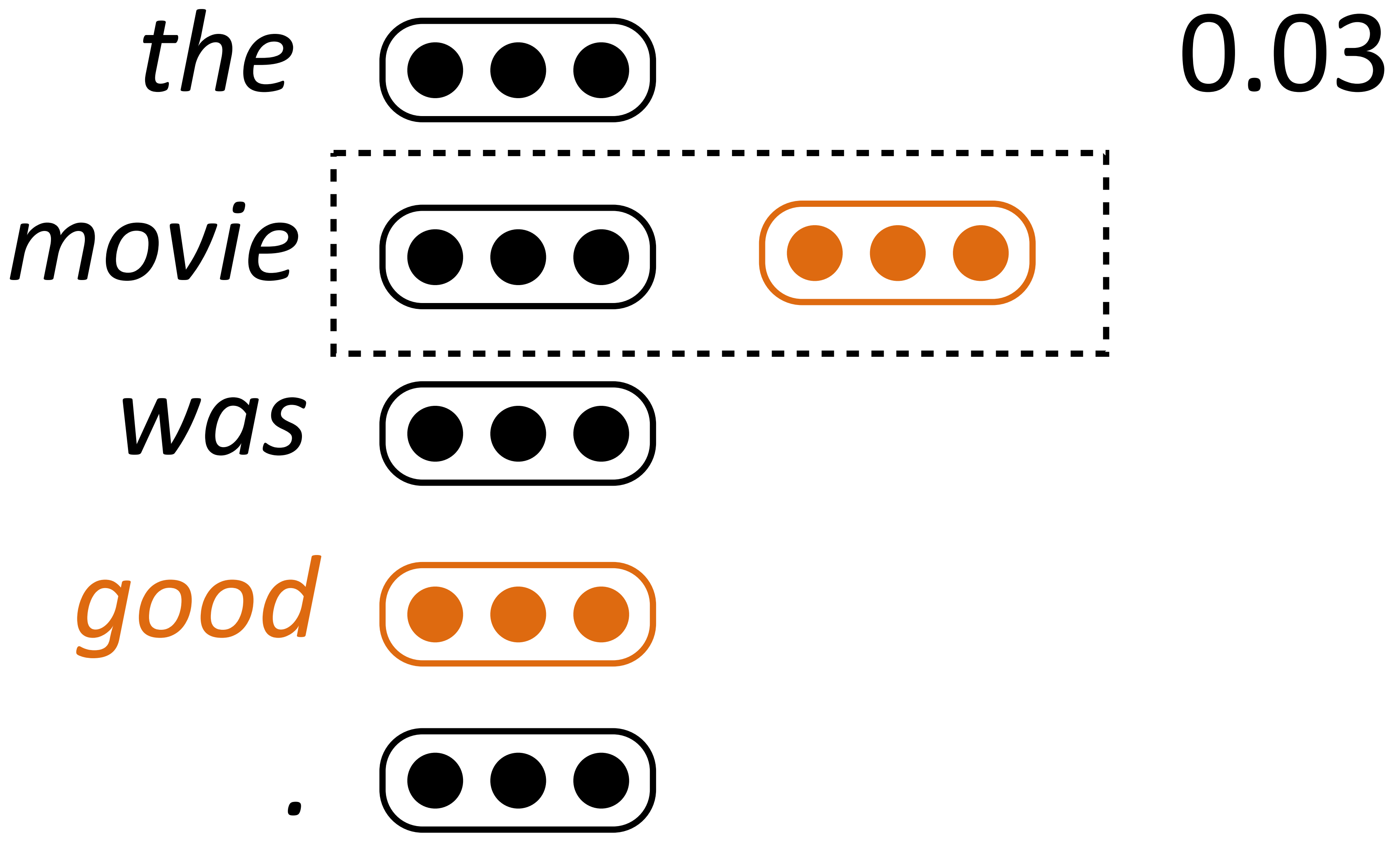

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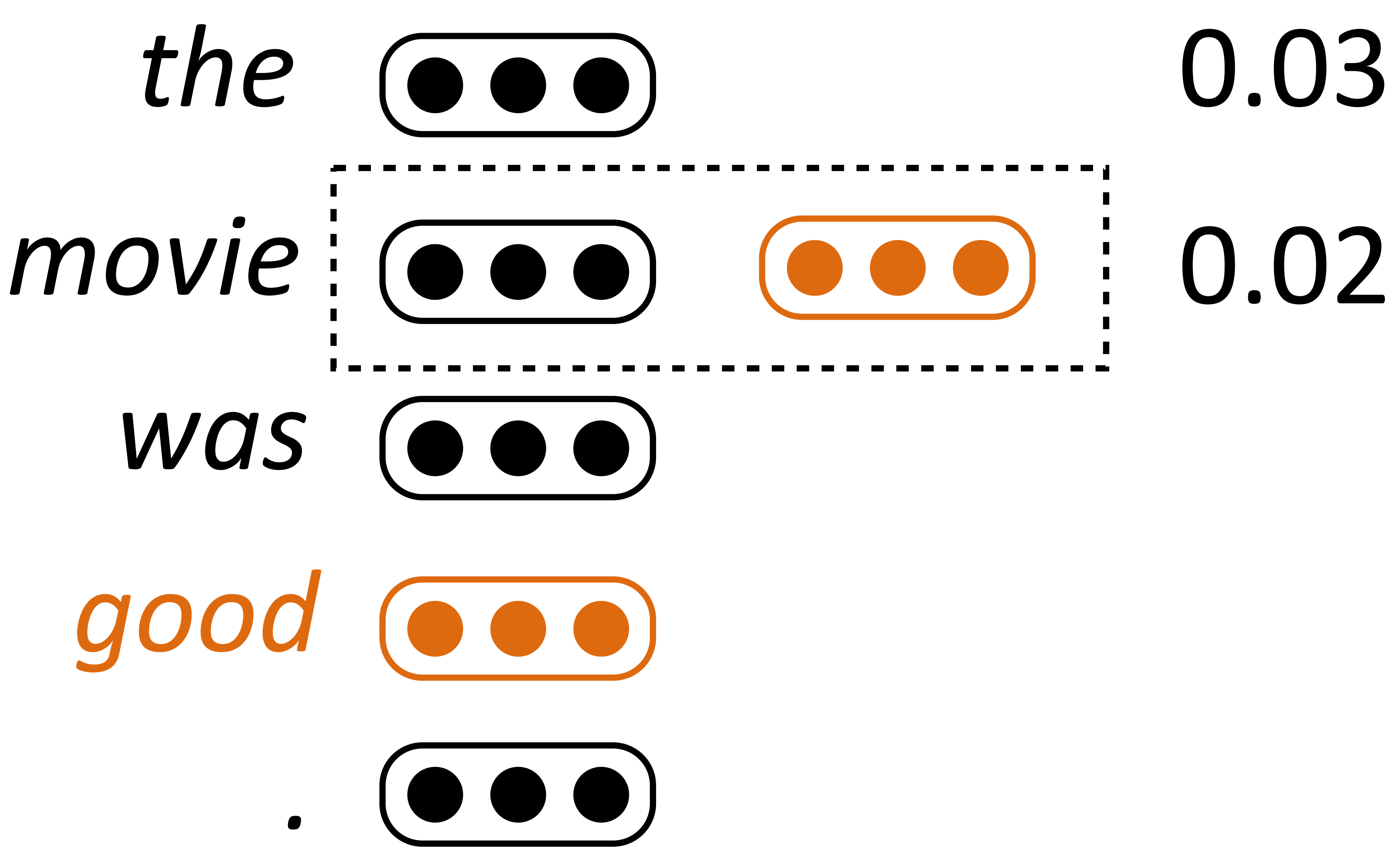

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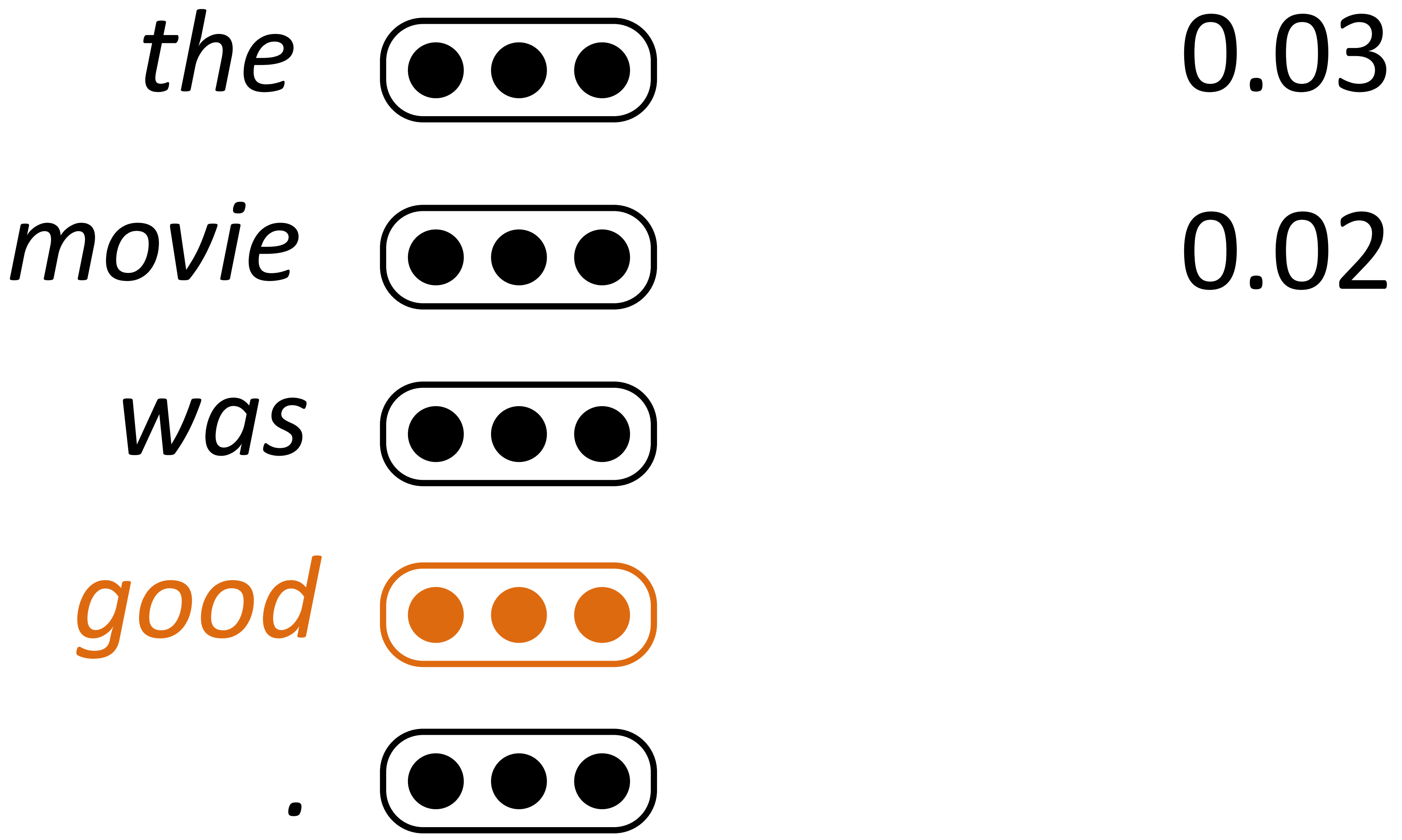

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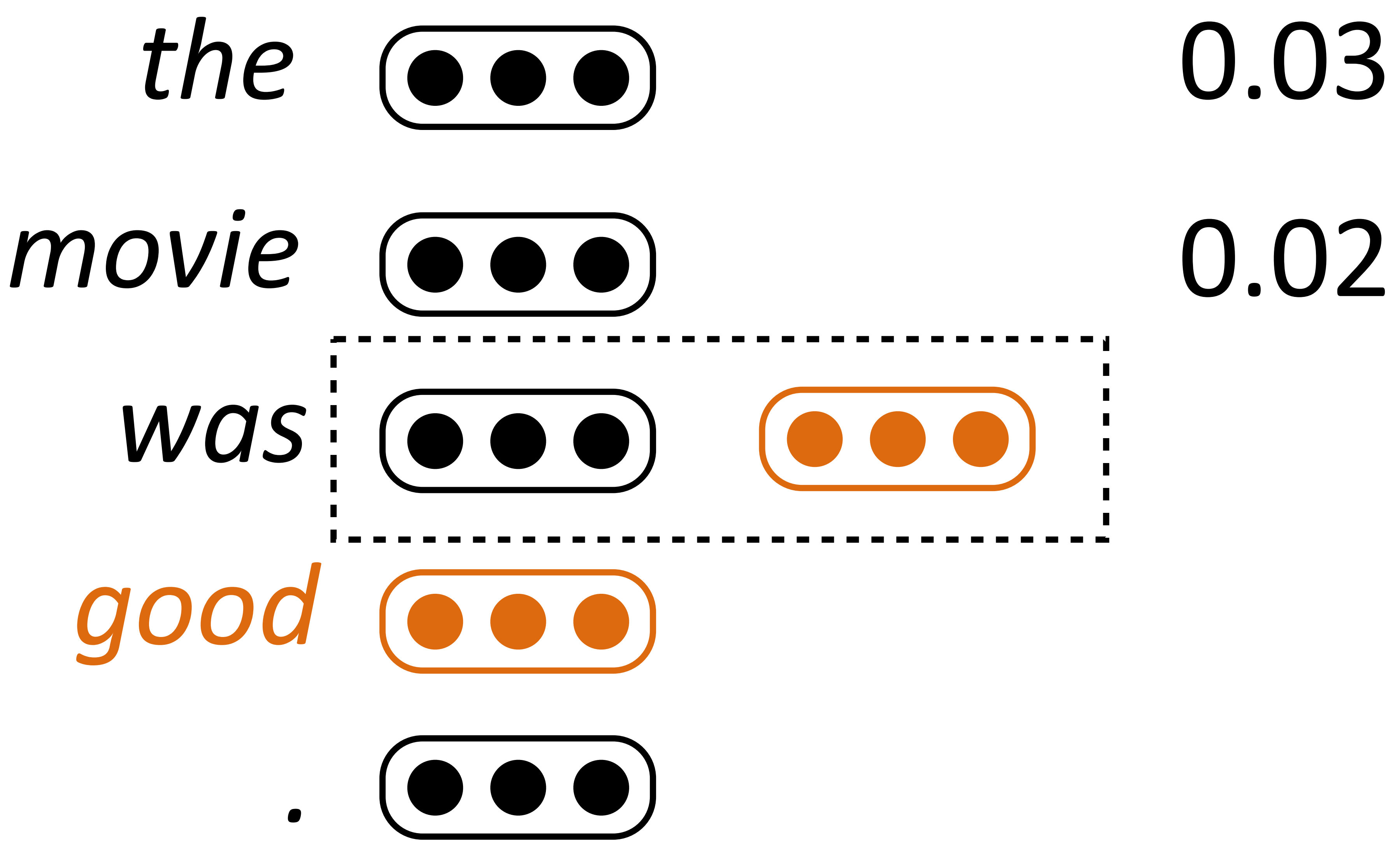

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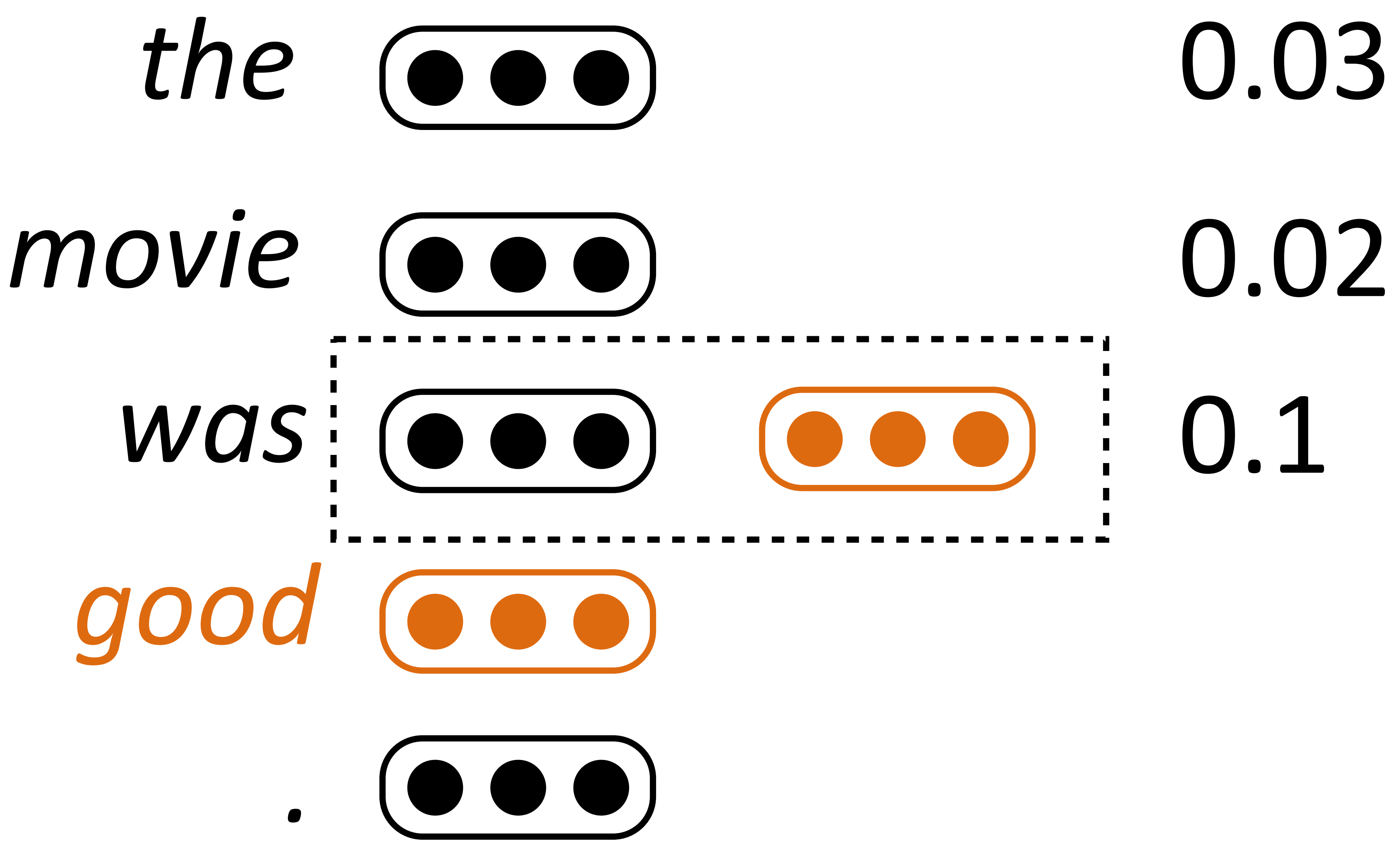

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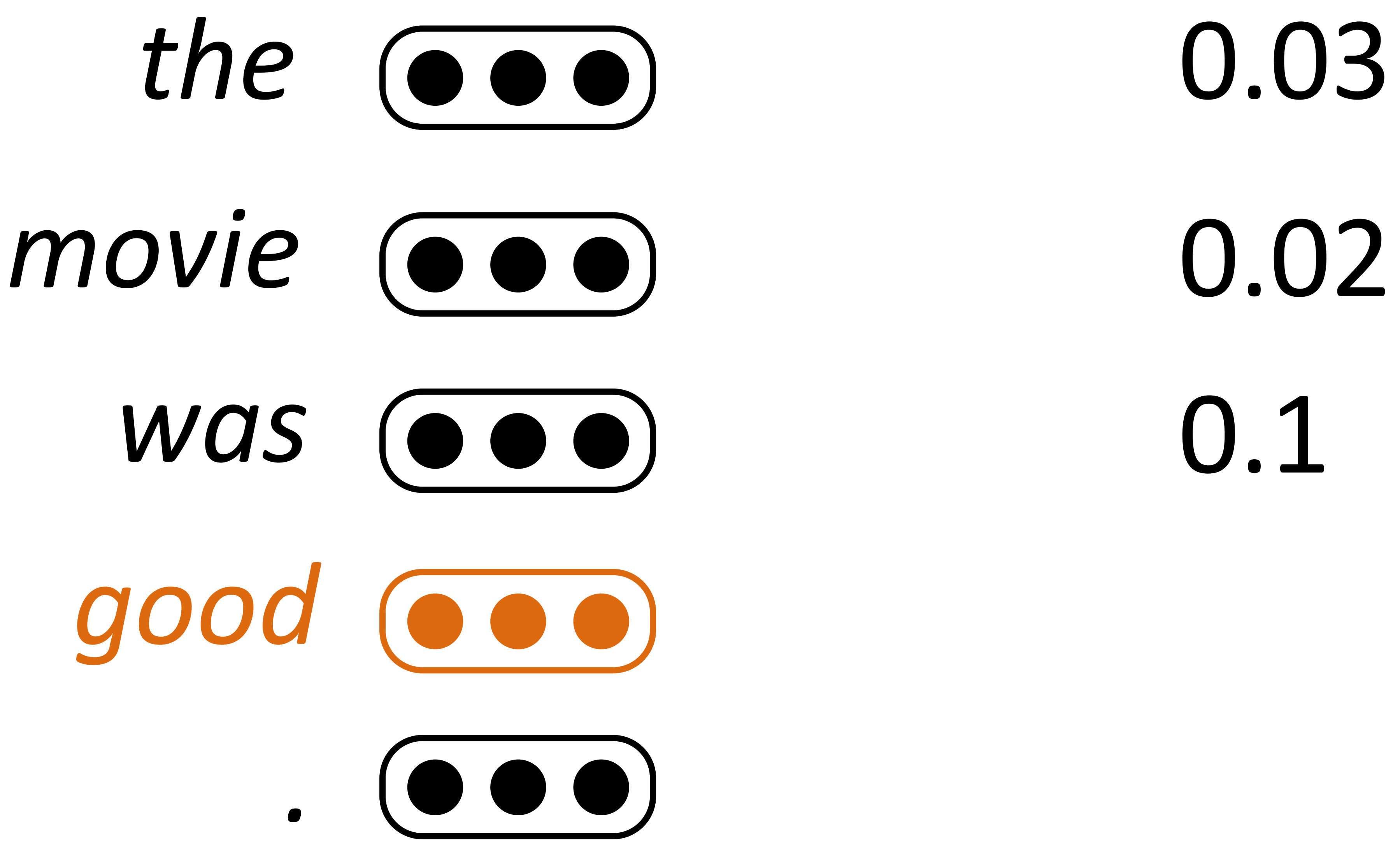

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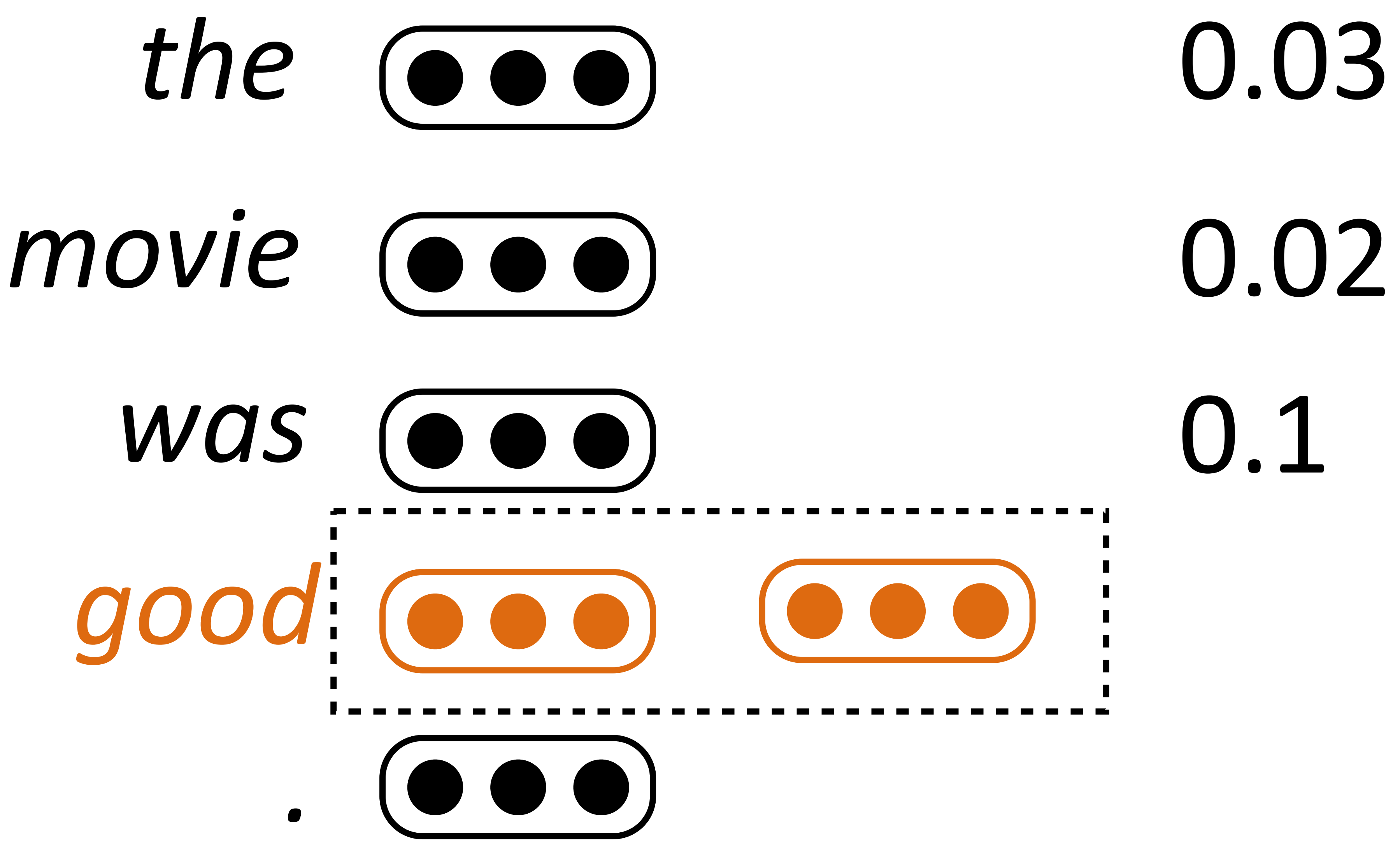
Understanding CNNs for Sentiment



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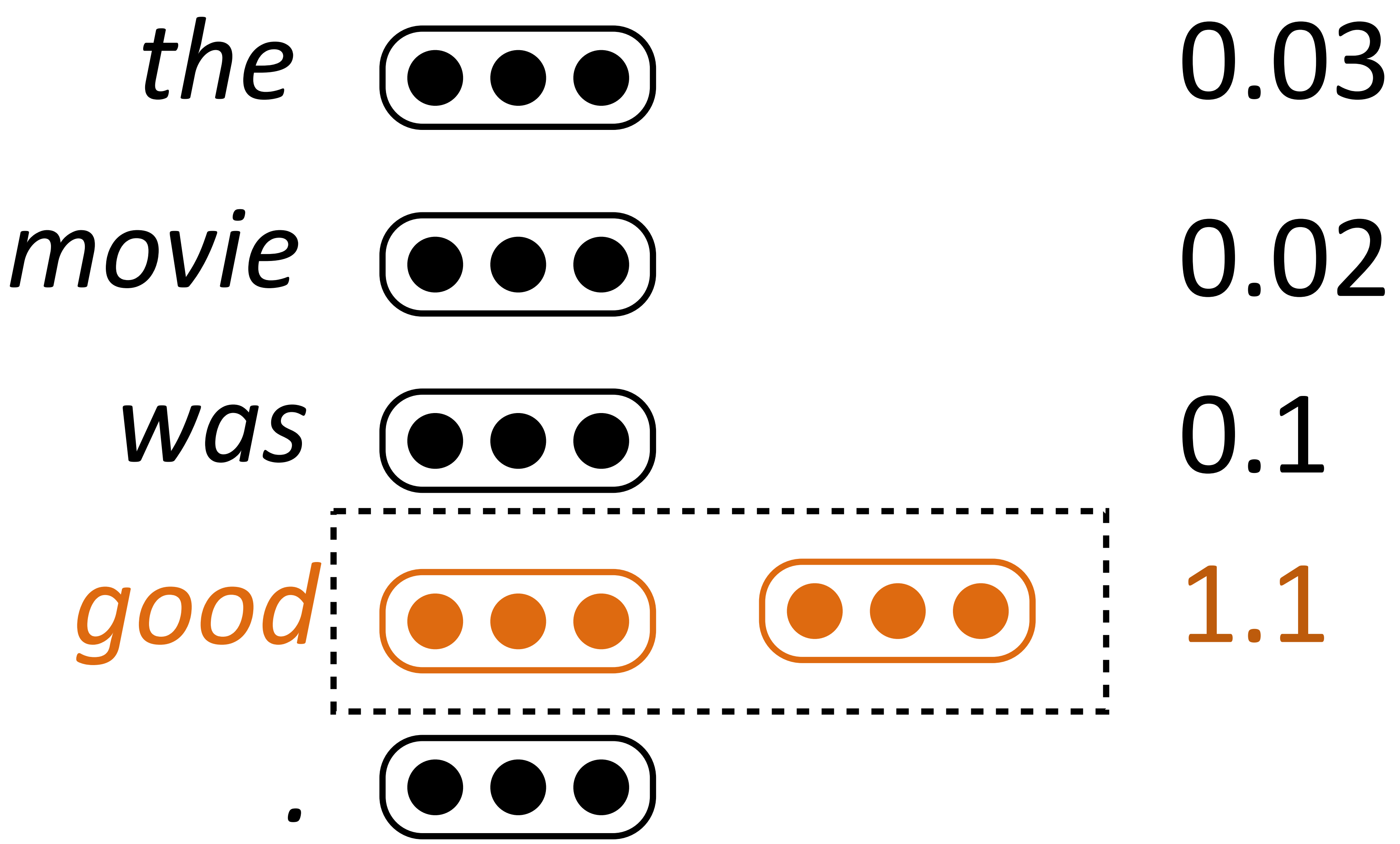

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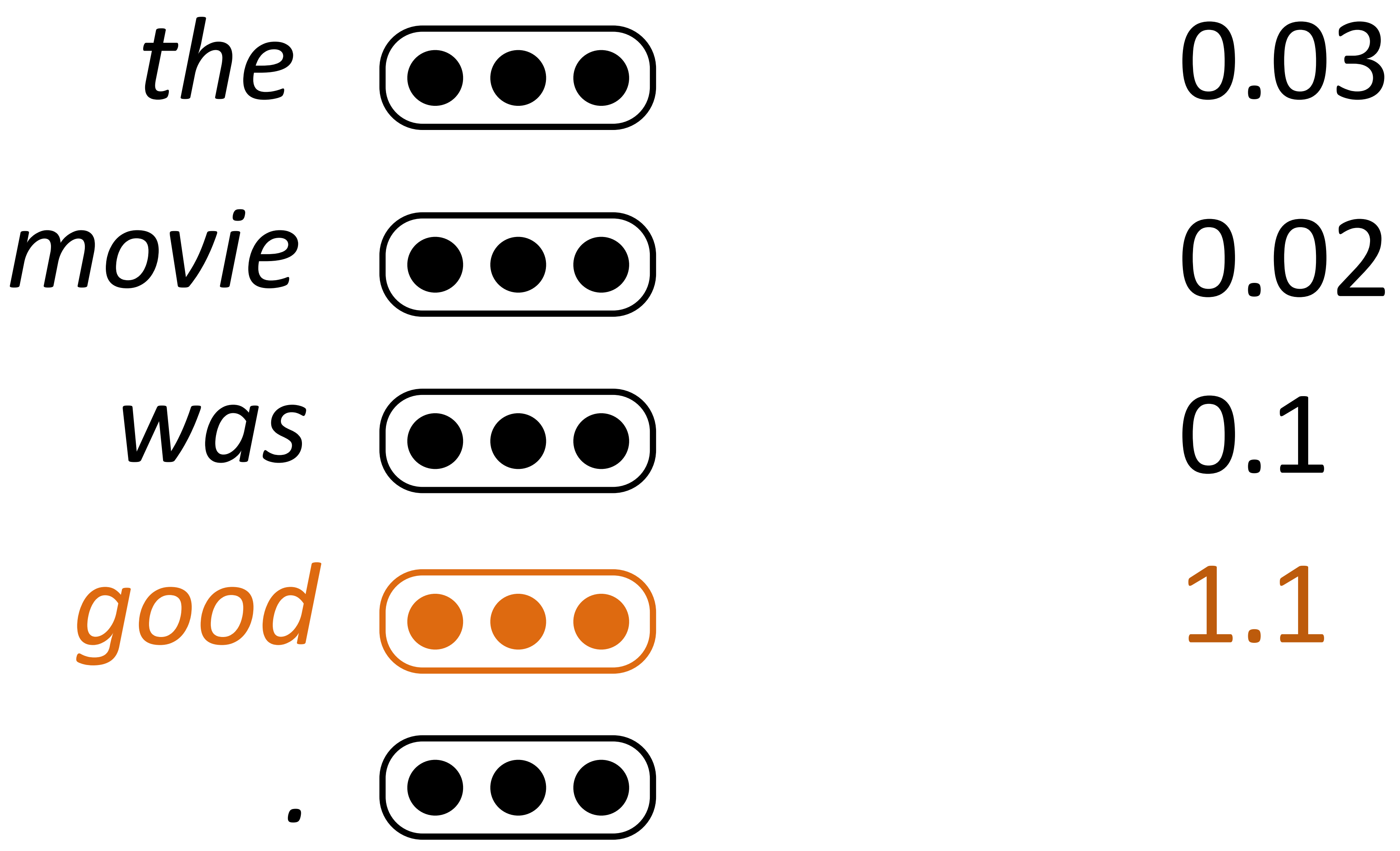

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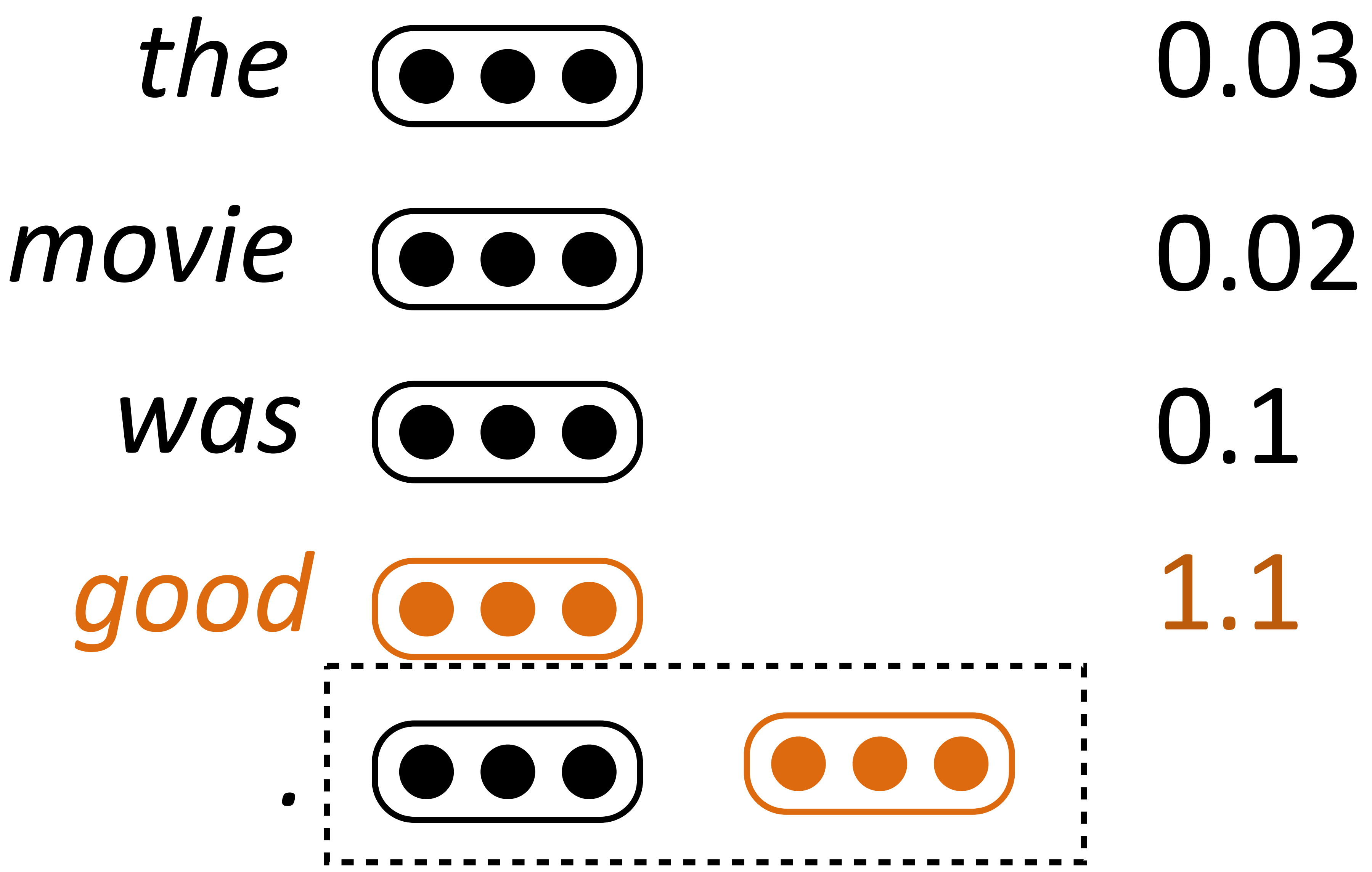

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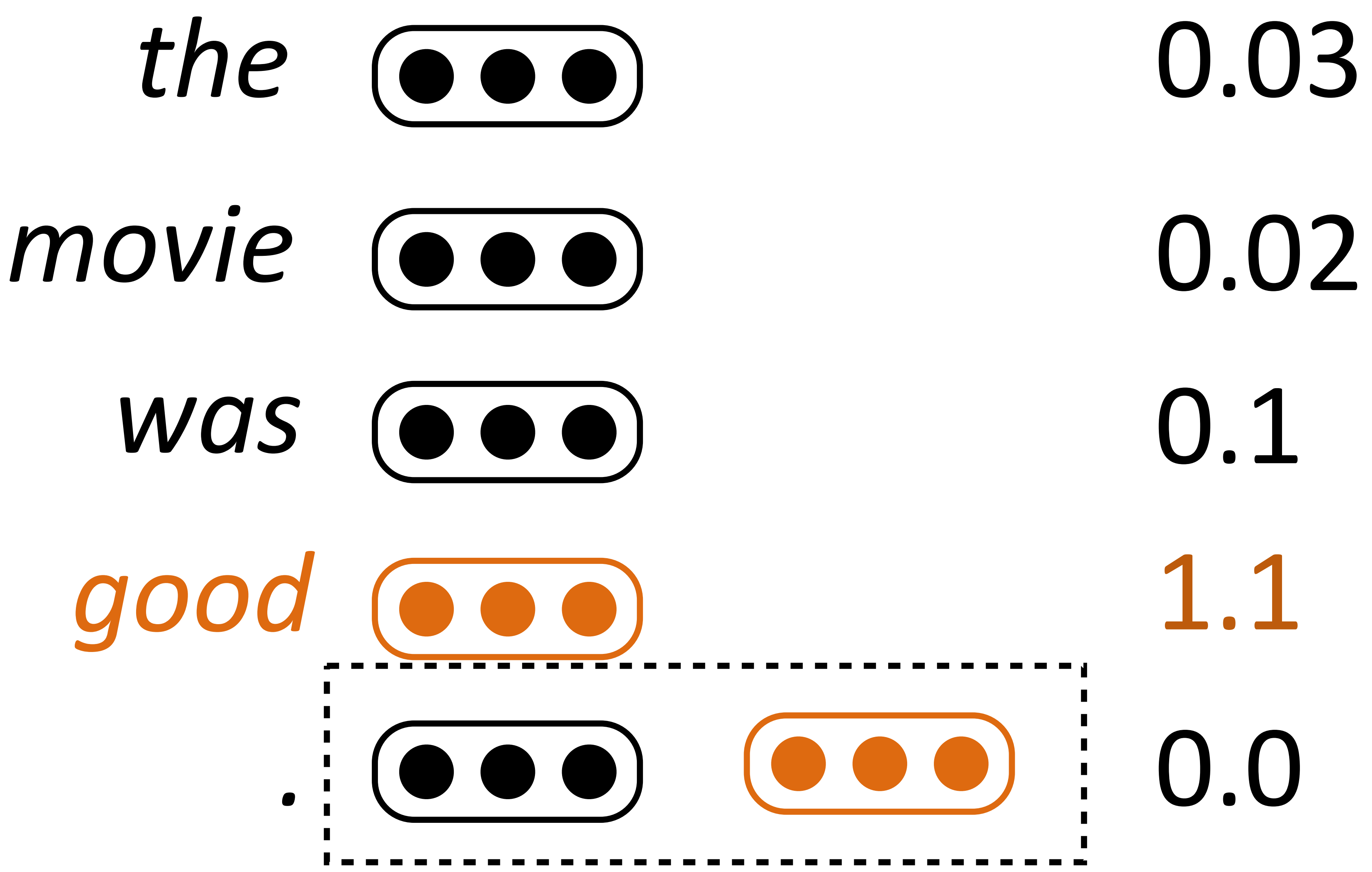


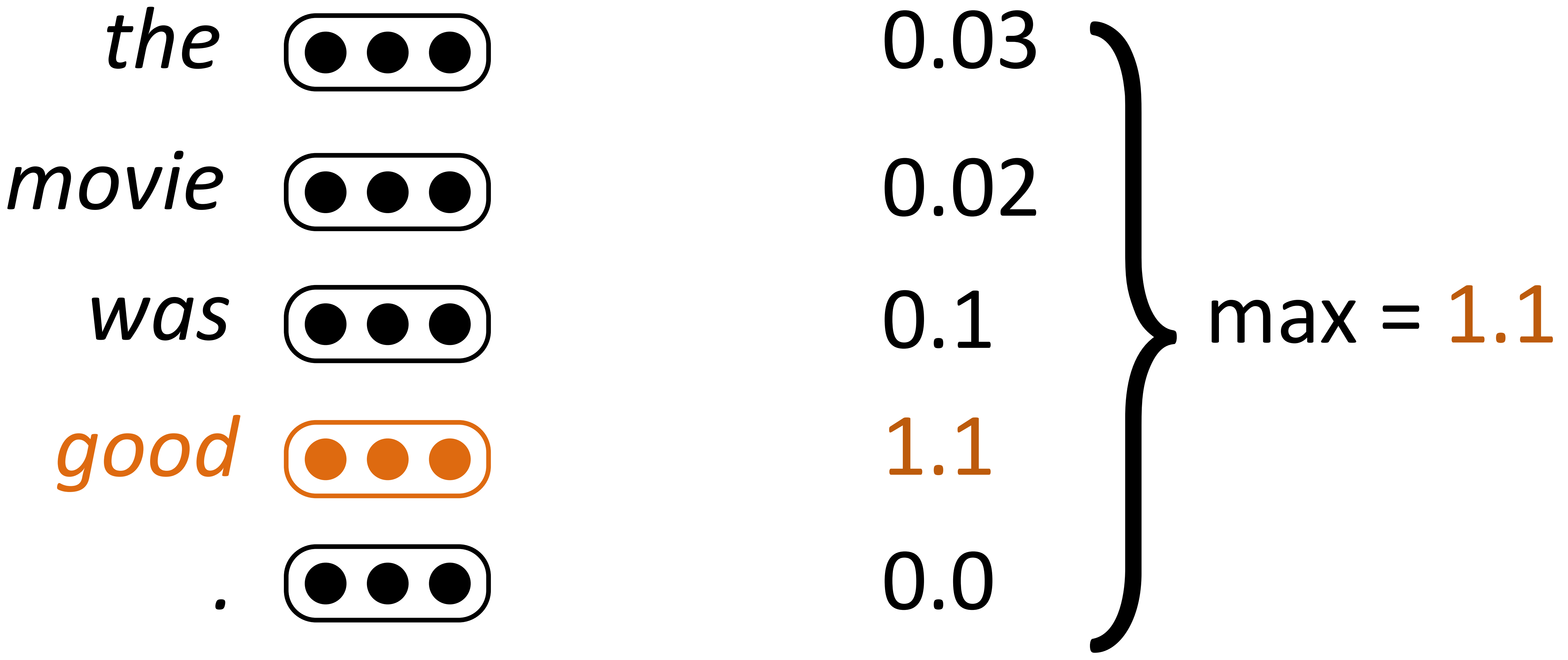
- Filter "looks like" the things that will cause it to have high activation

Understanding CNNs for Sentiment

the	0.03
movie	0.02
was	0.1
good	1.1
.	0.0

- Filter “looks like” the things that will cause it to have high activation

Understanding CNNs for Sentiment



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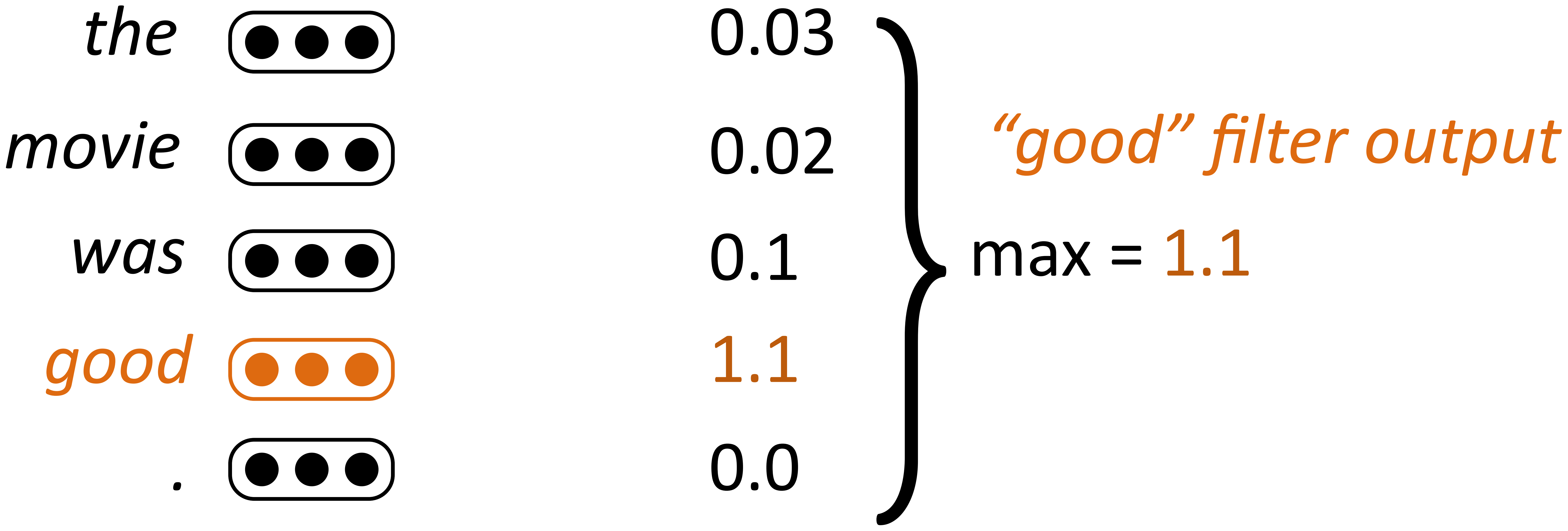

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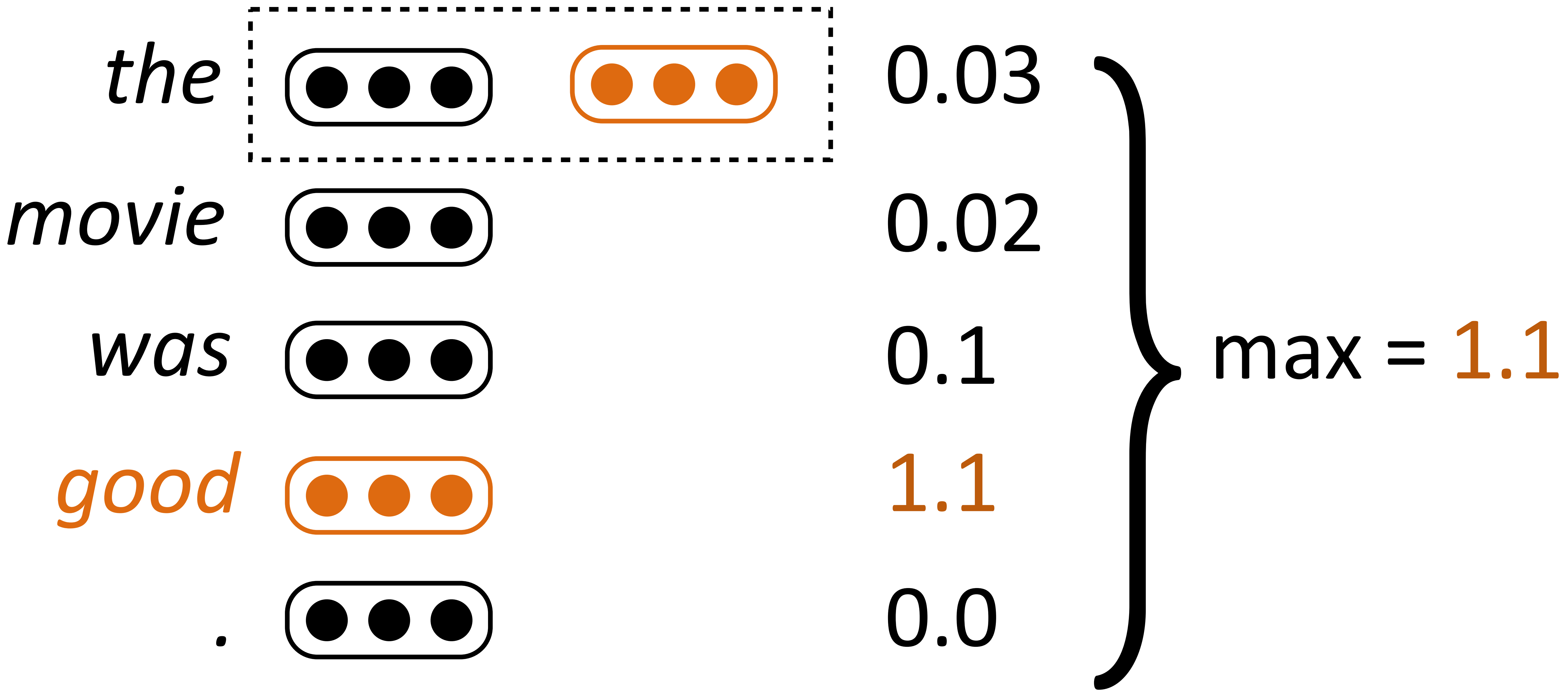

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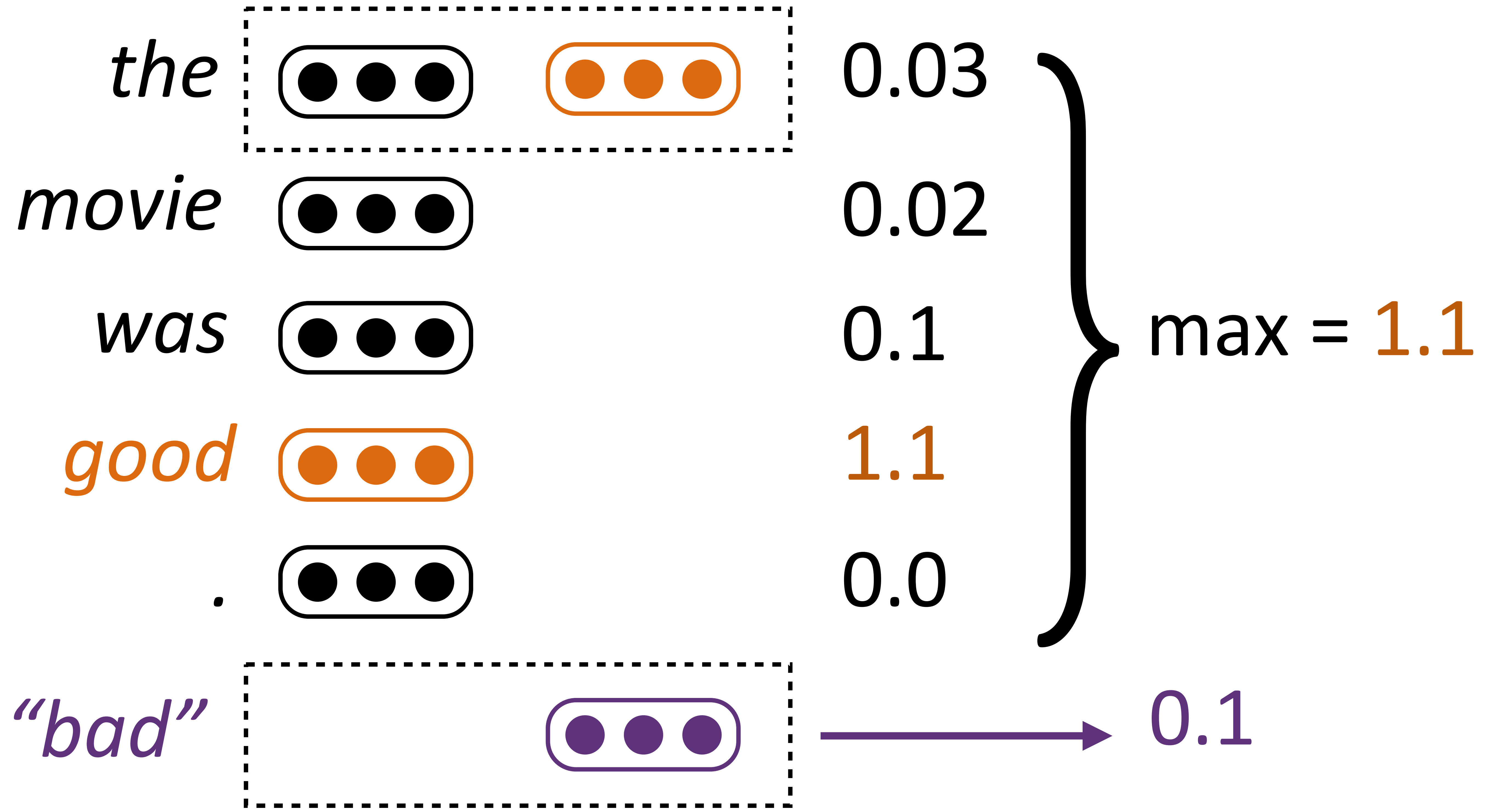

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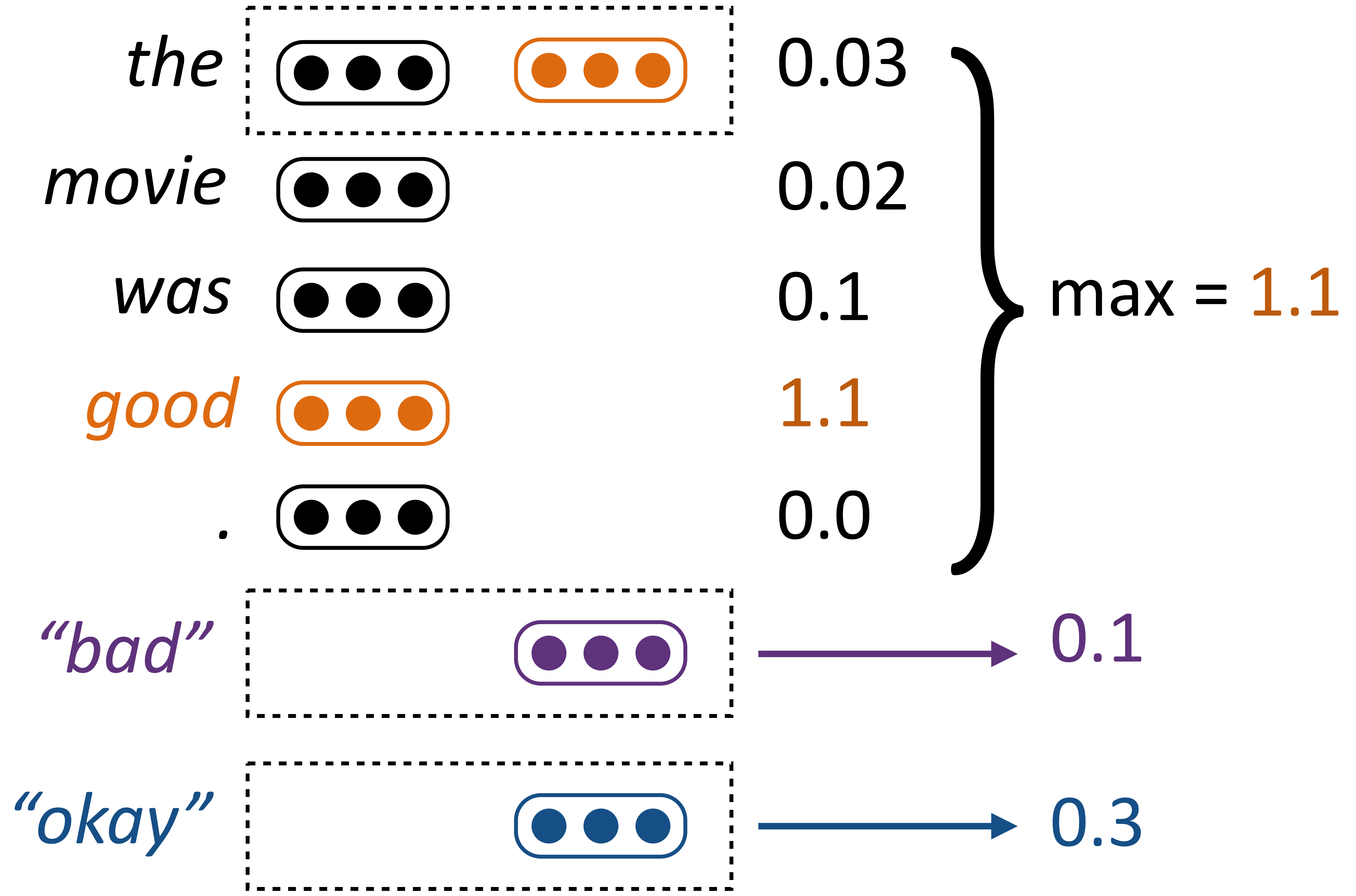

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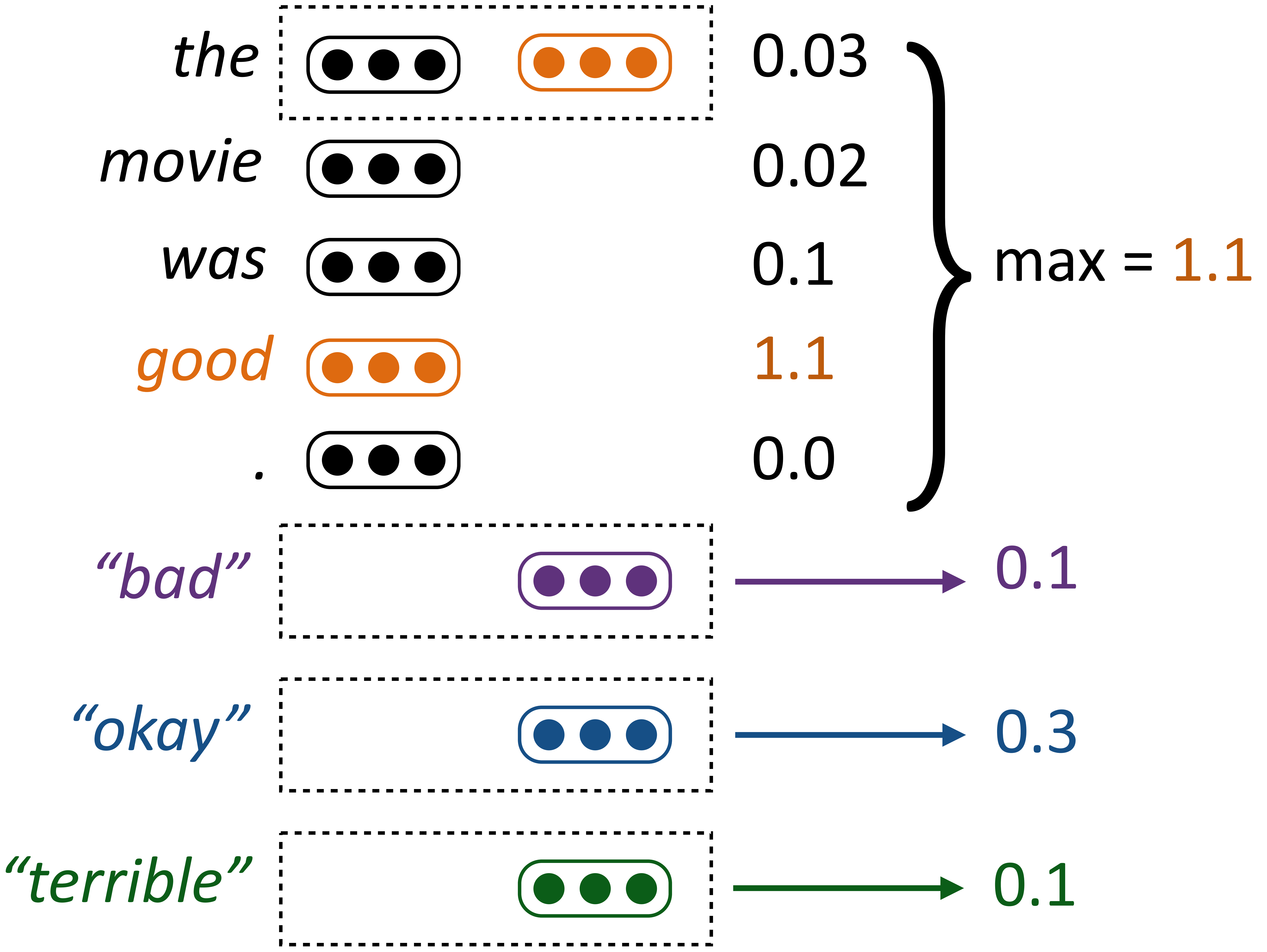

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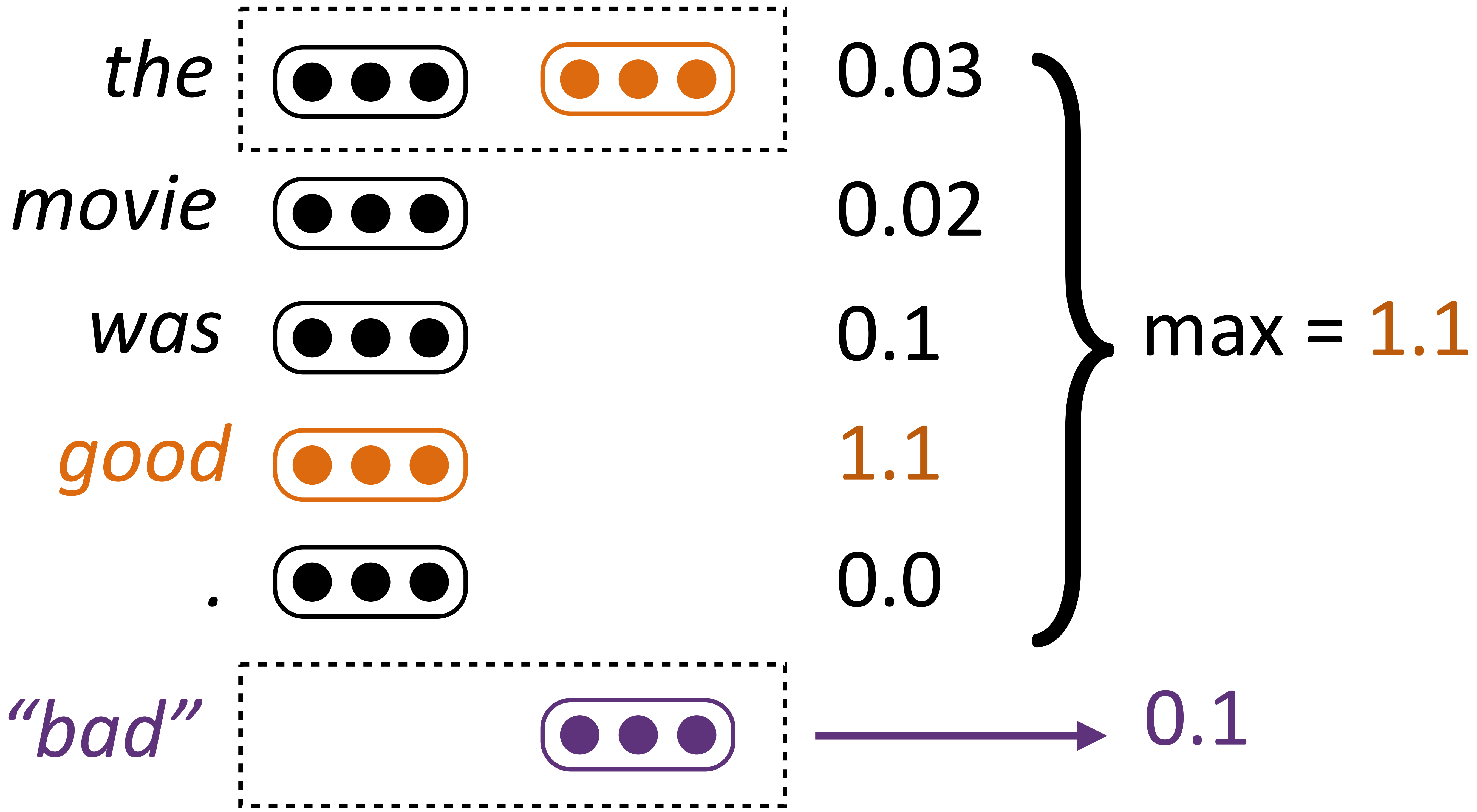

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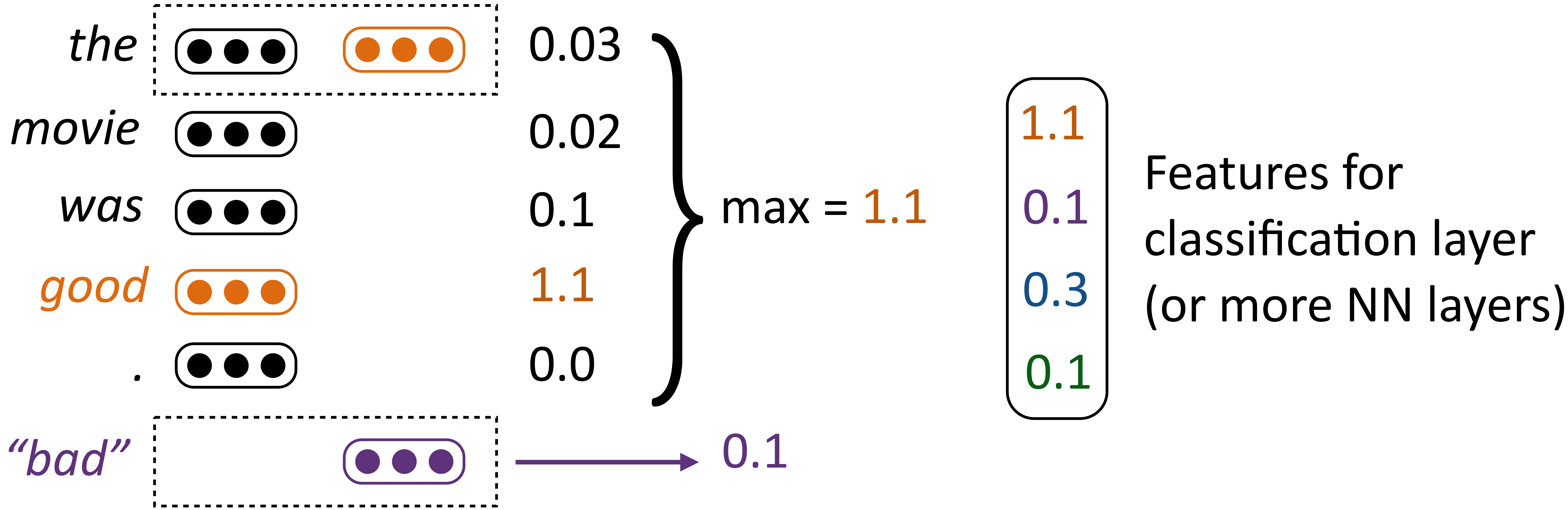

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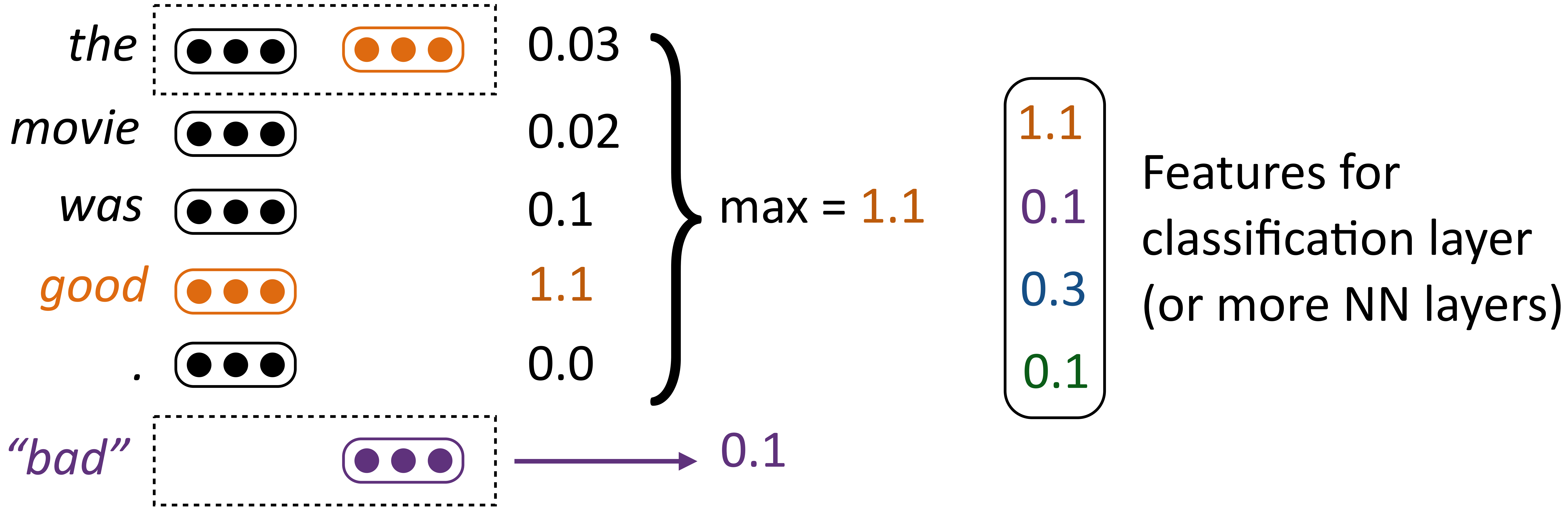
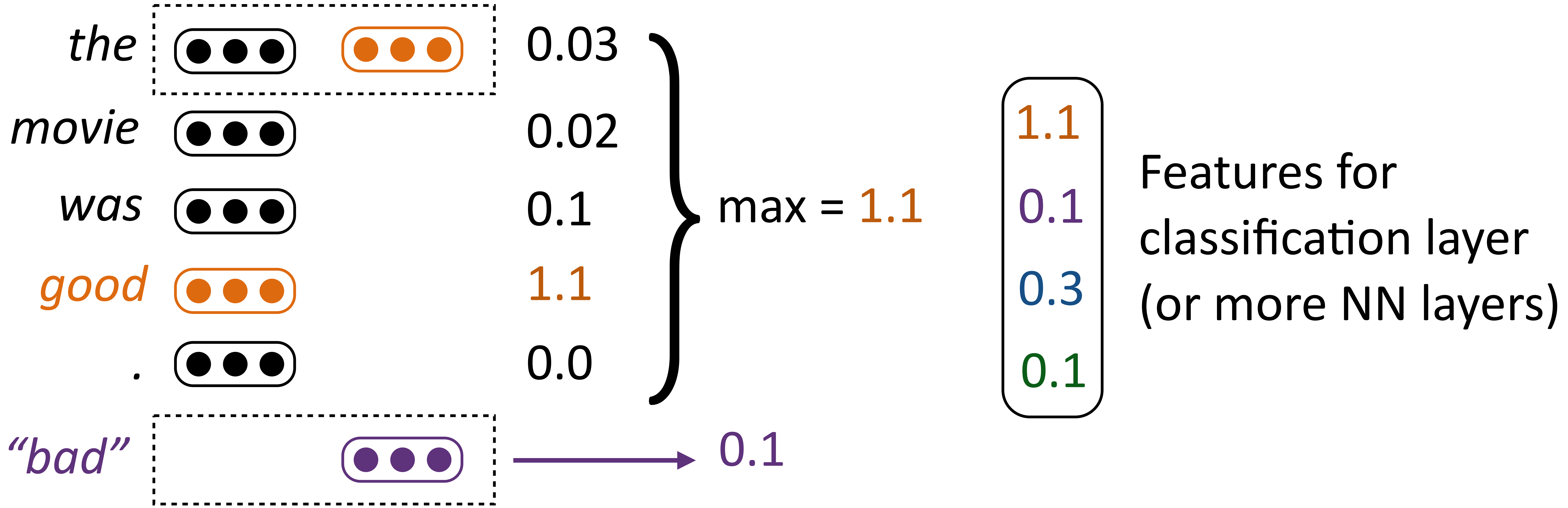


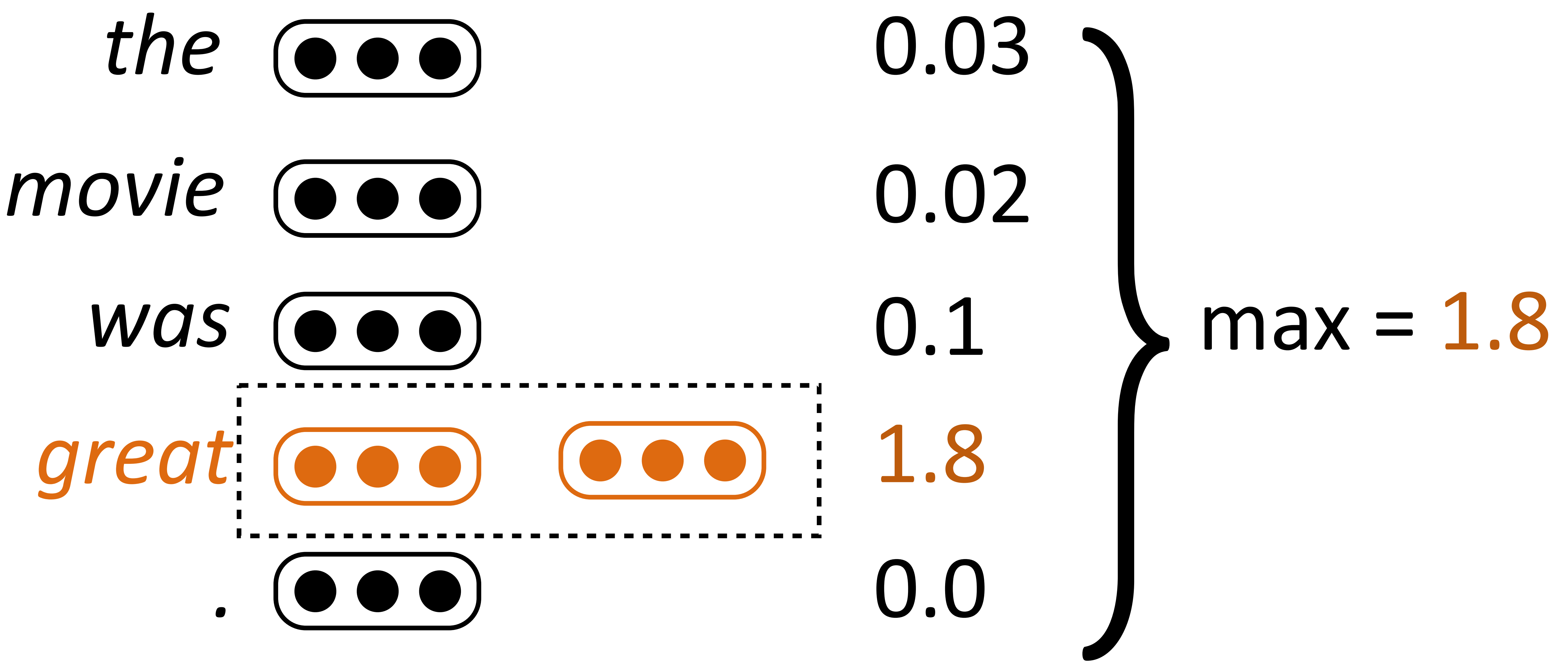
- Takes variable-length input and turns it into fixed-length output

Understanding CNNs for Sentiment



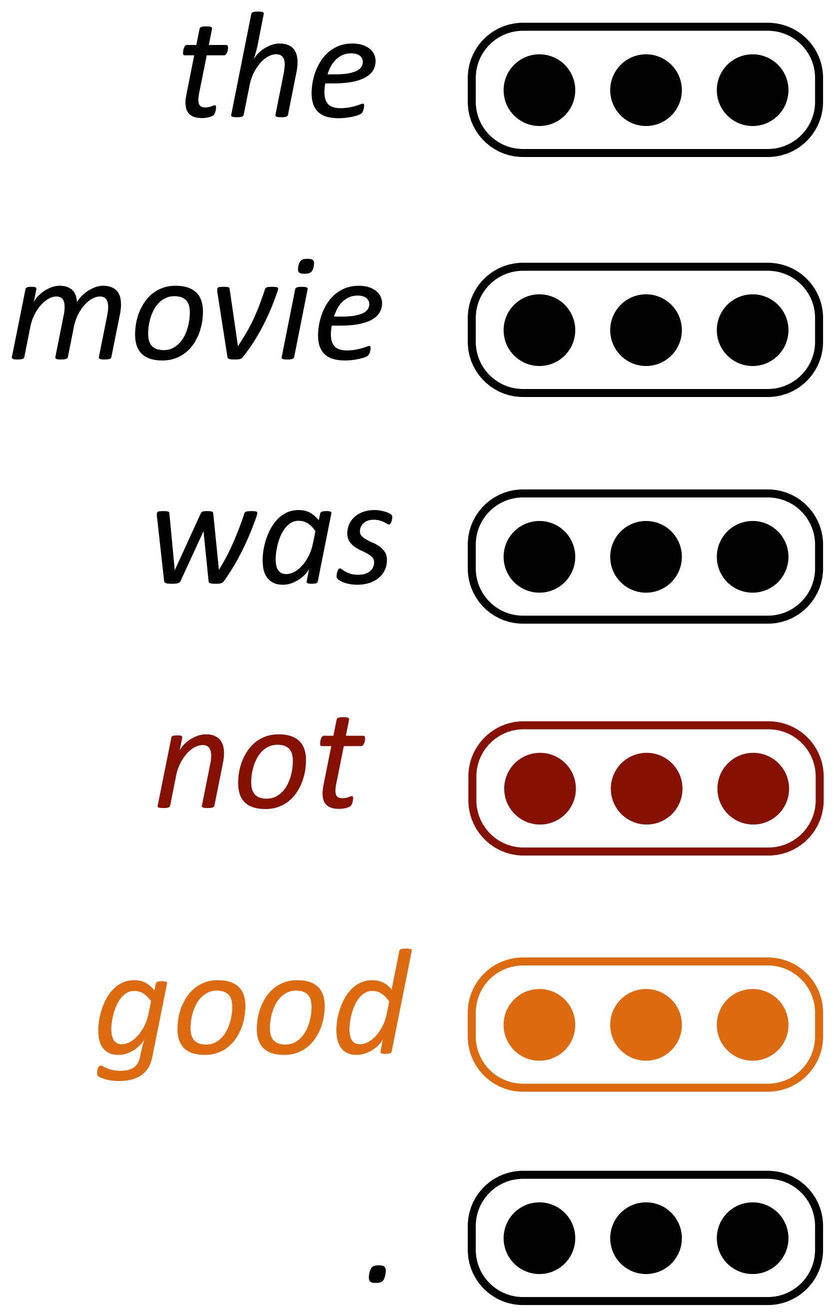
- Takes variable-length input and turns it into fixed-length output
- Filters are initialized randomly and then learned

Understanding CNNs for Sentiment



- Word vectors for similar words are similar, so convolutional filters will have similar outputs

Understanding CNNs for Sentiment



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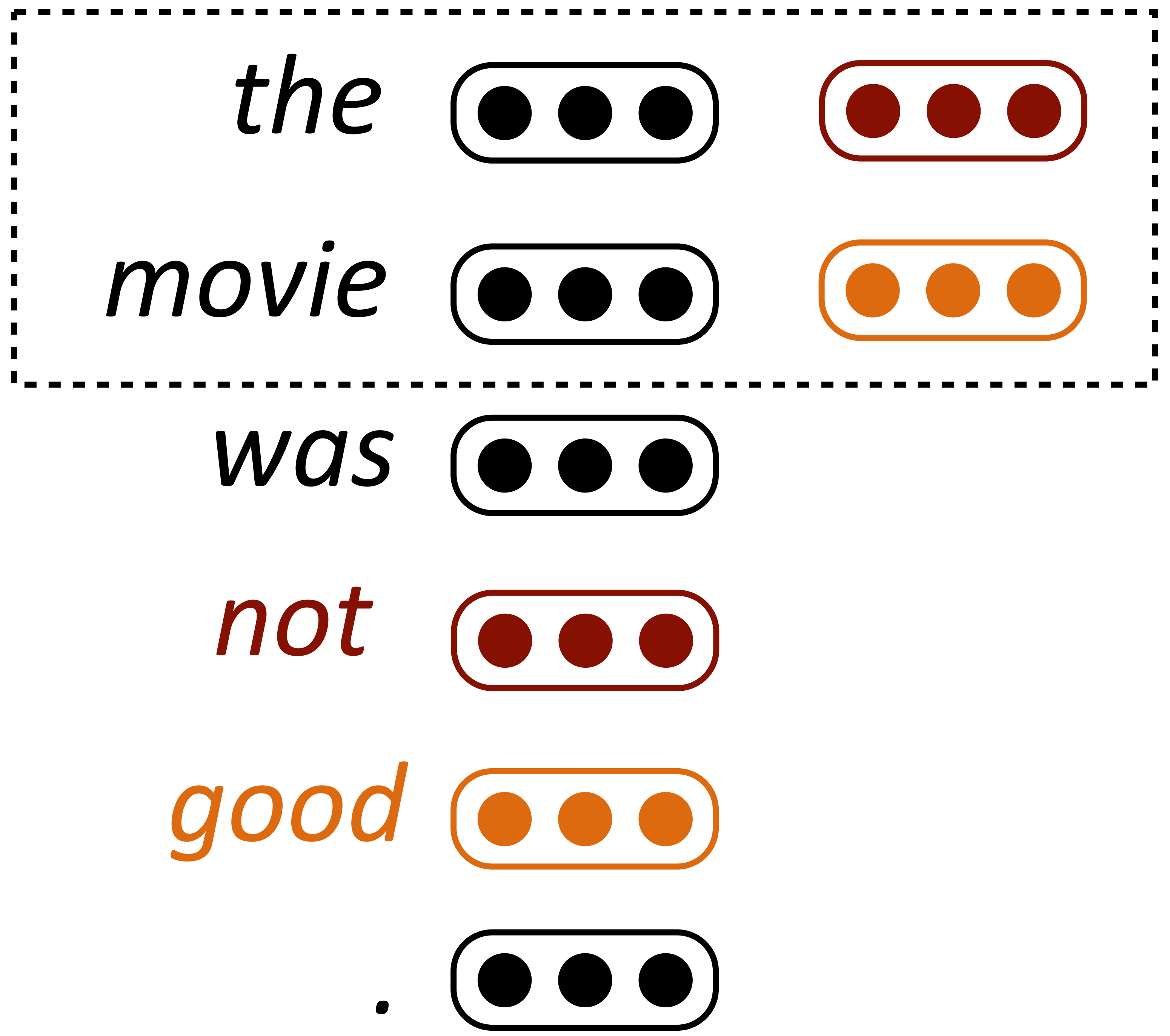

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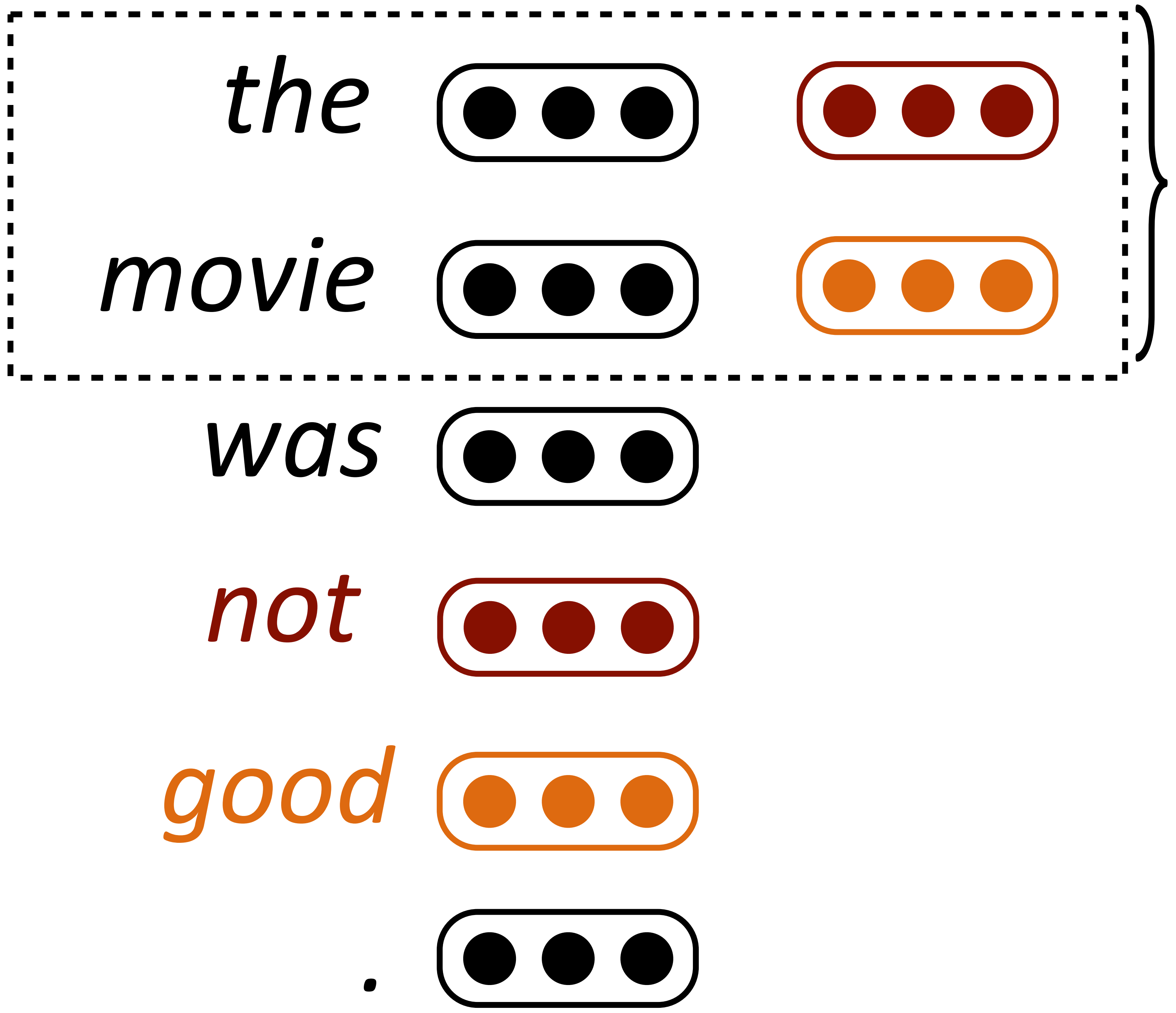

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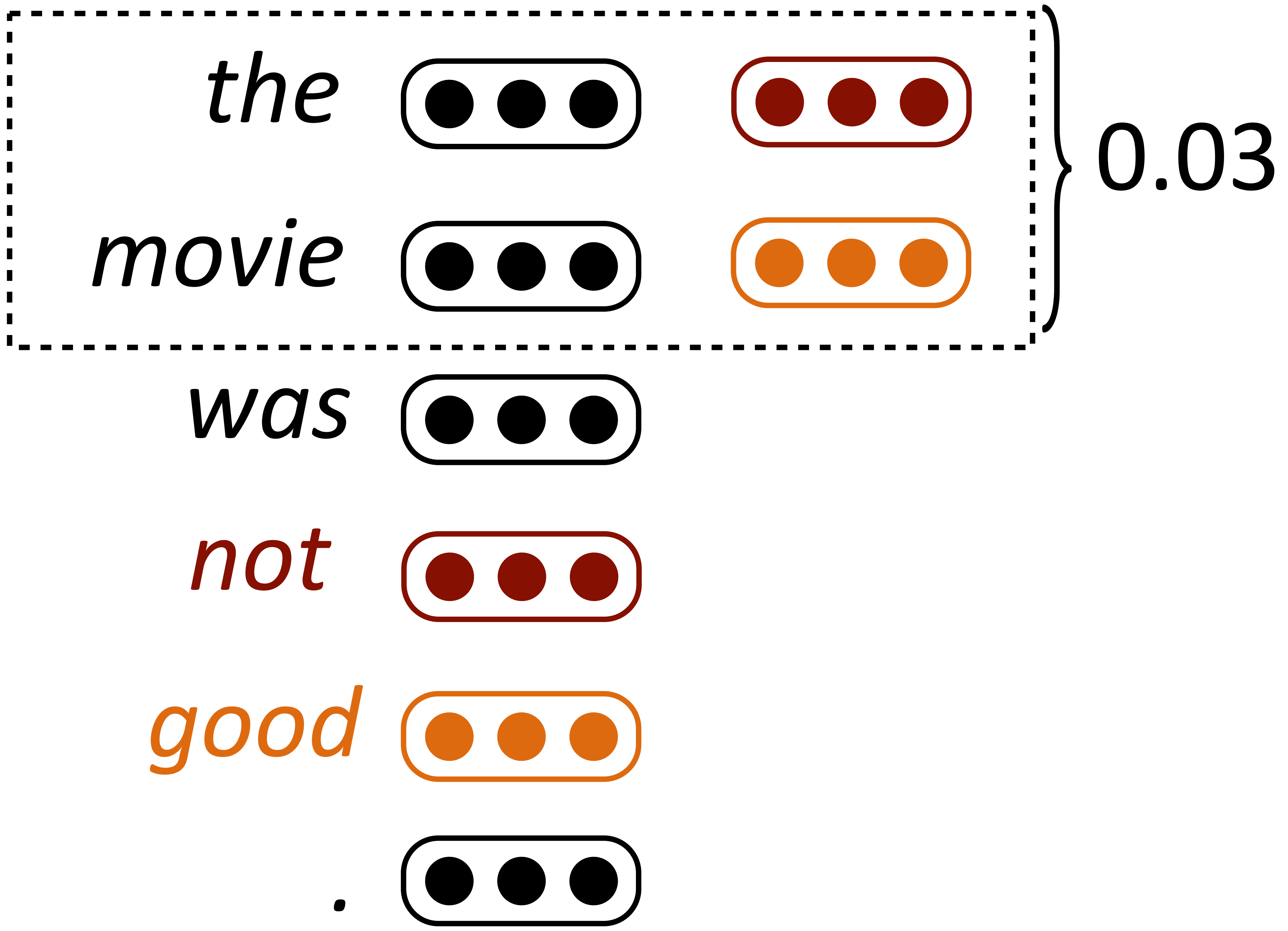

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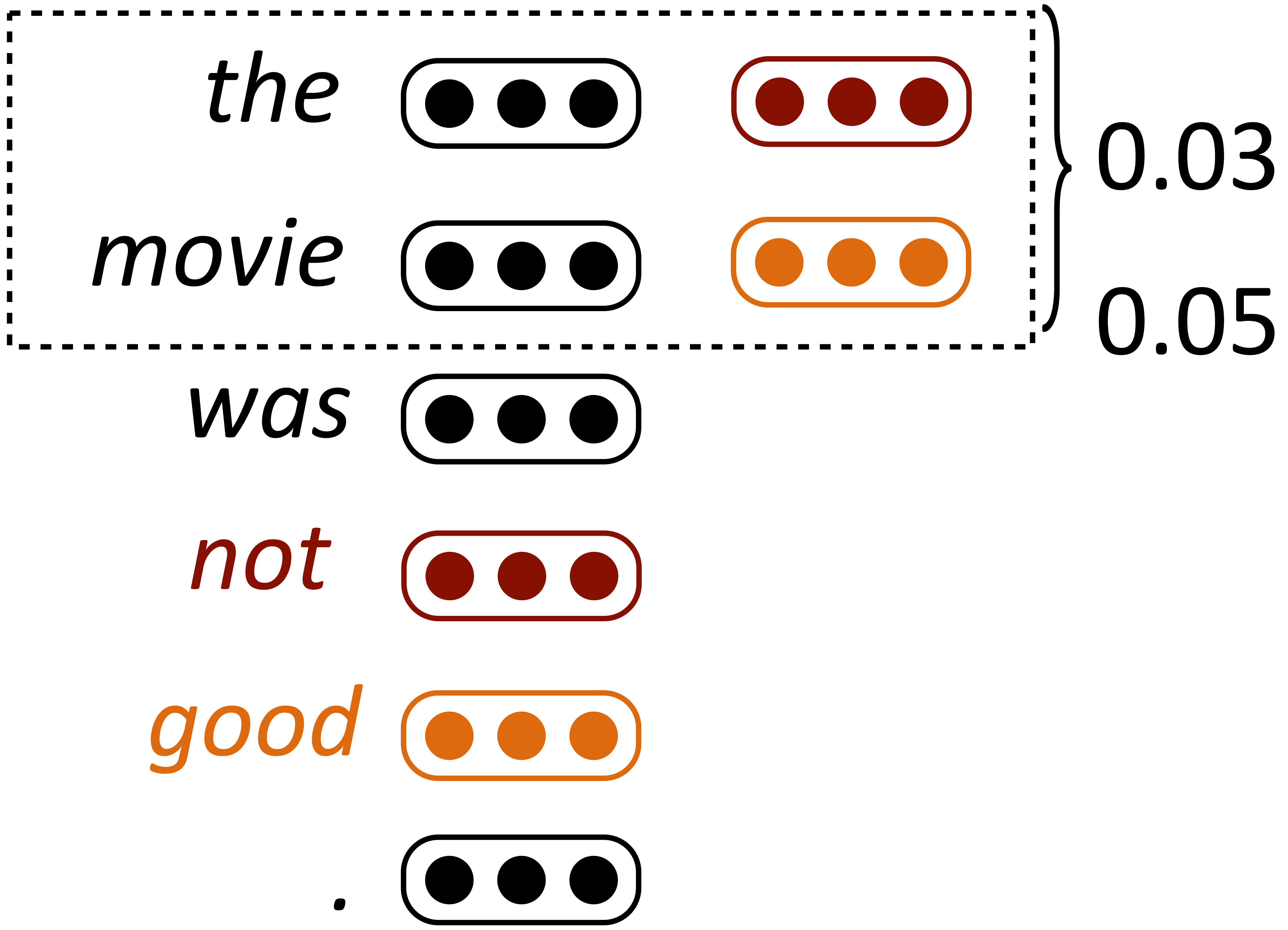

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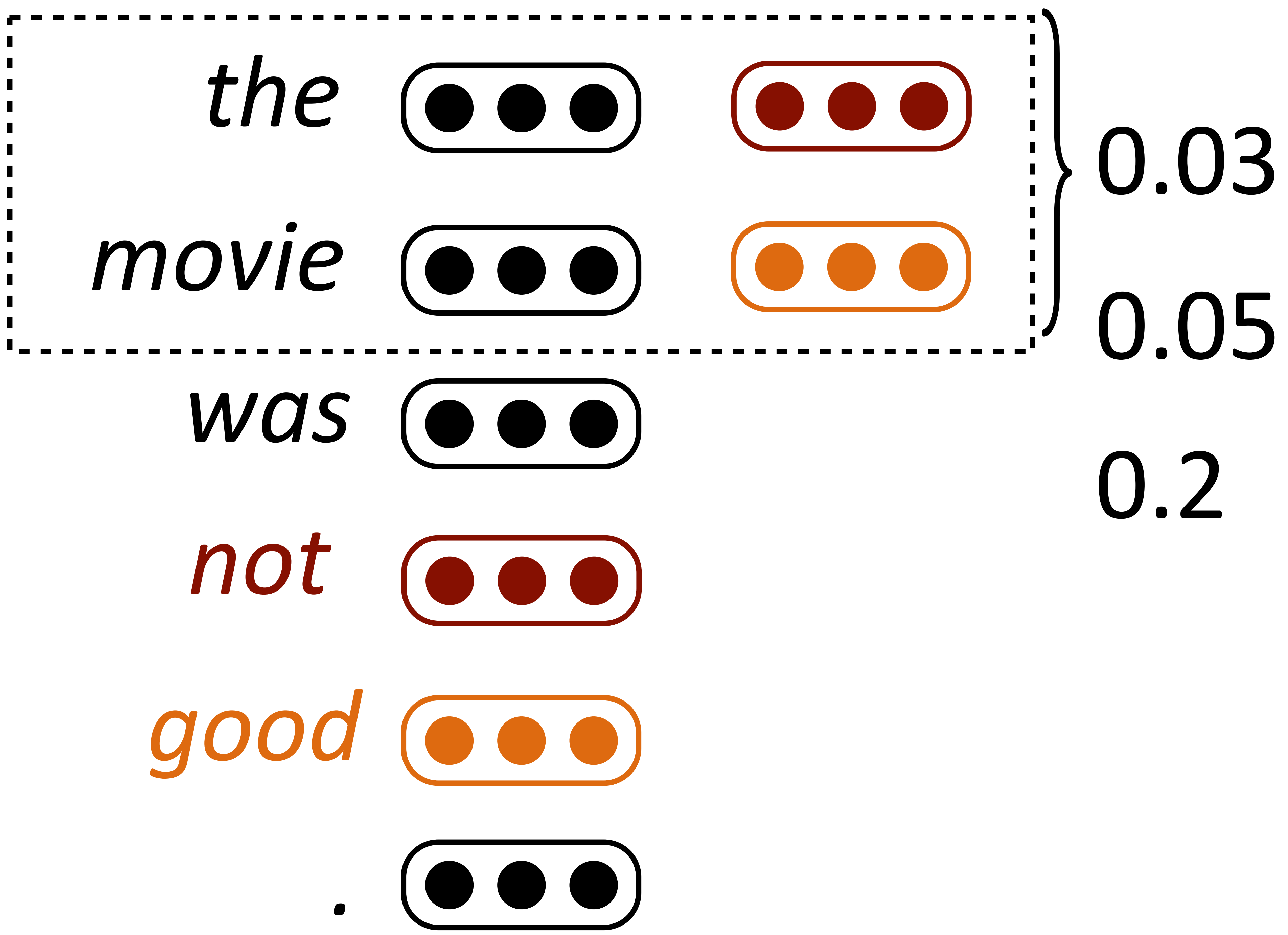

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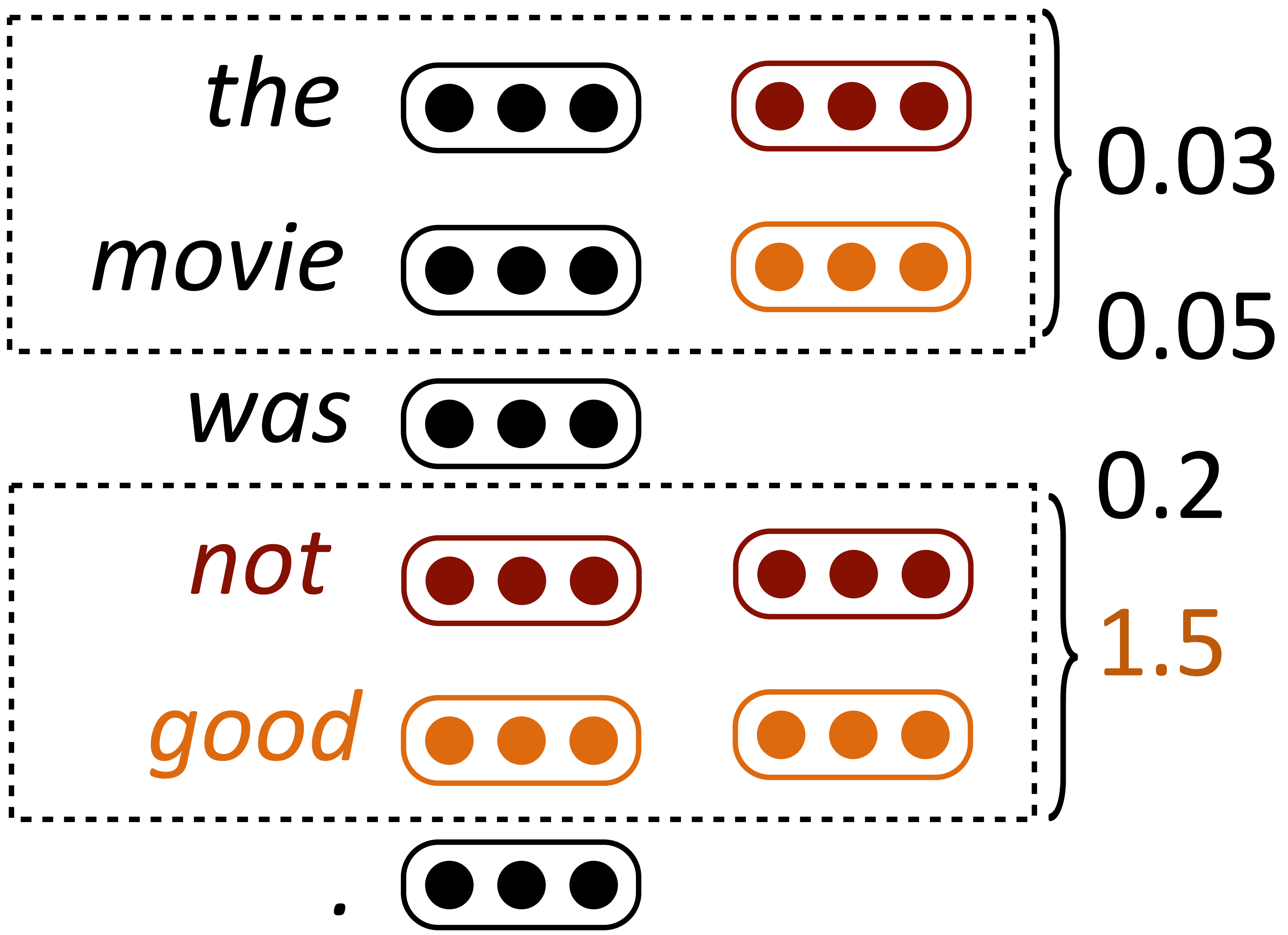

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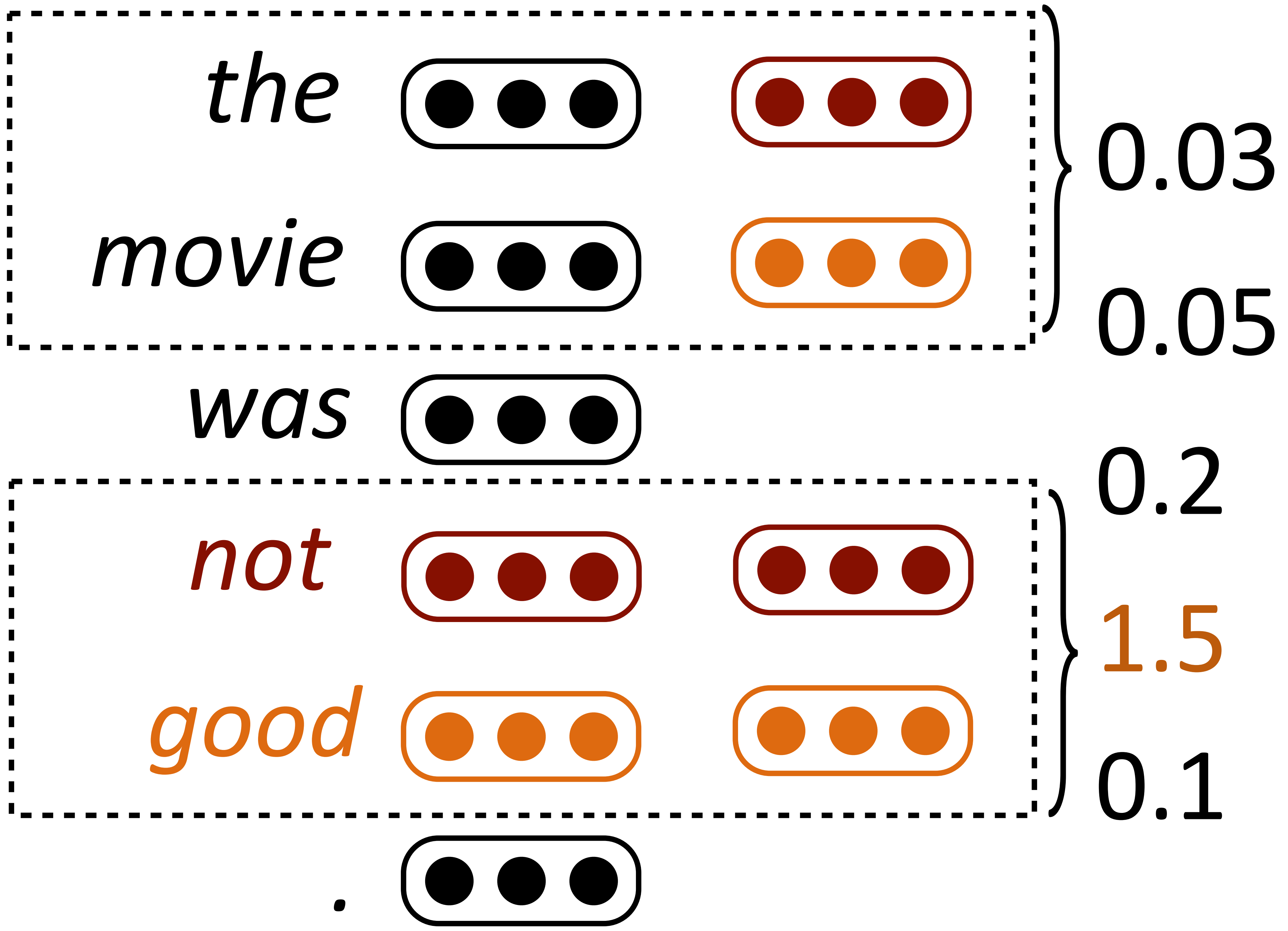

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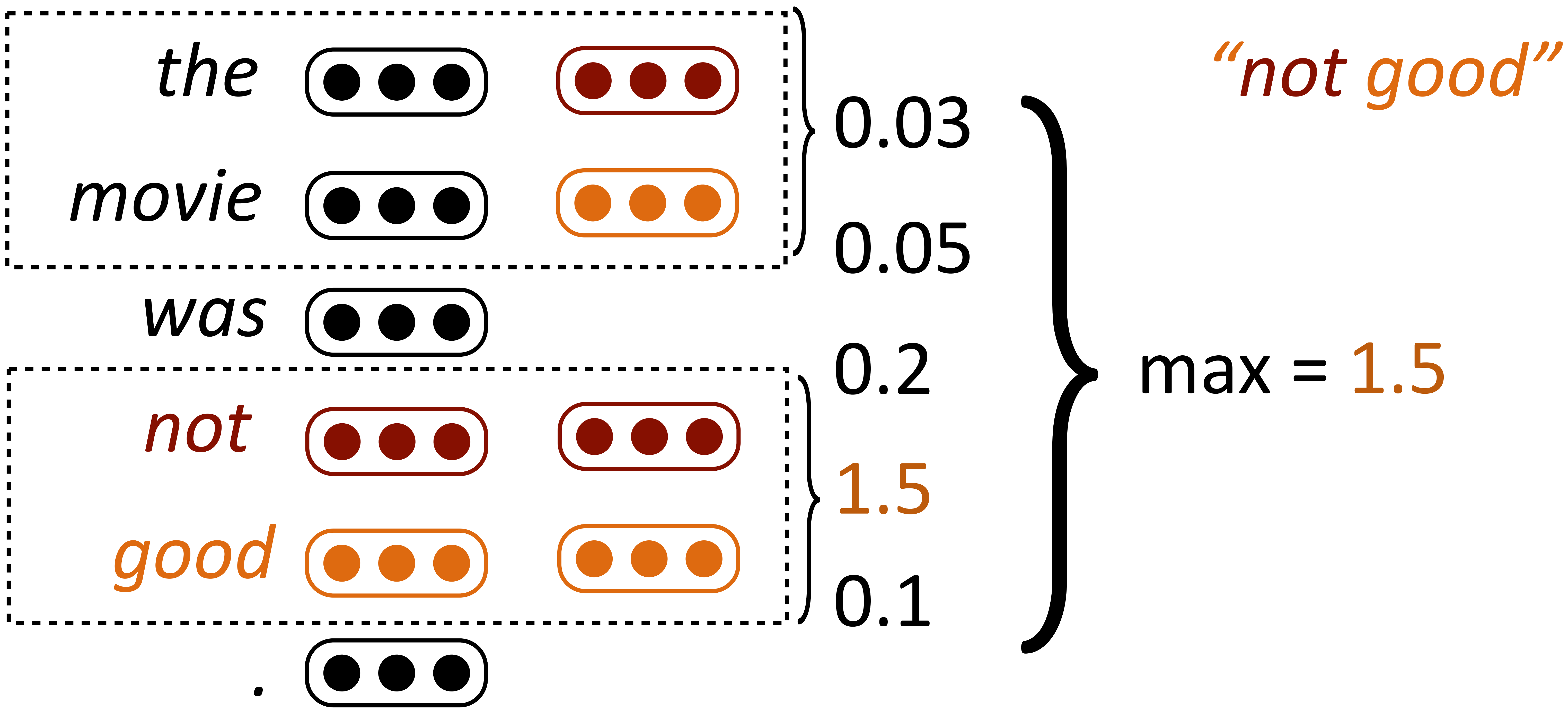

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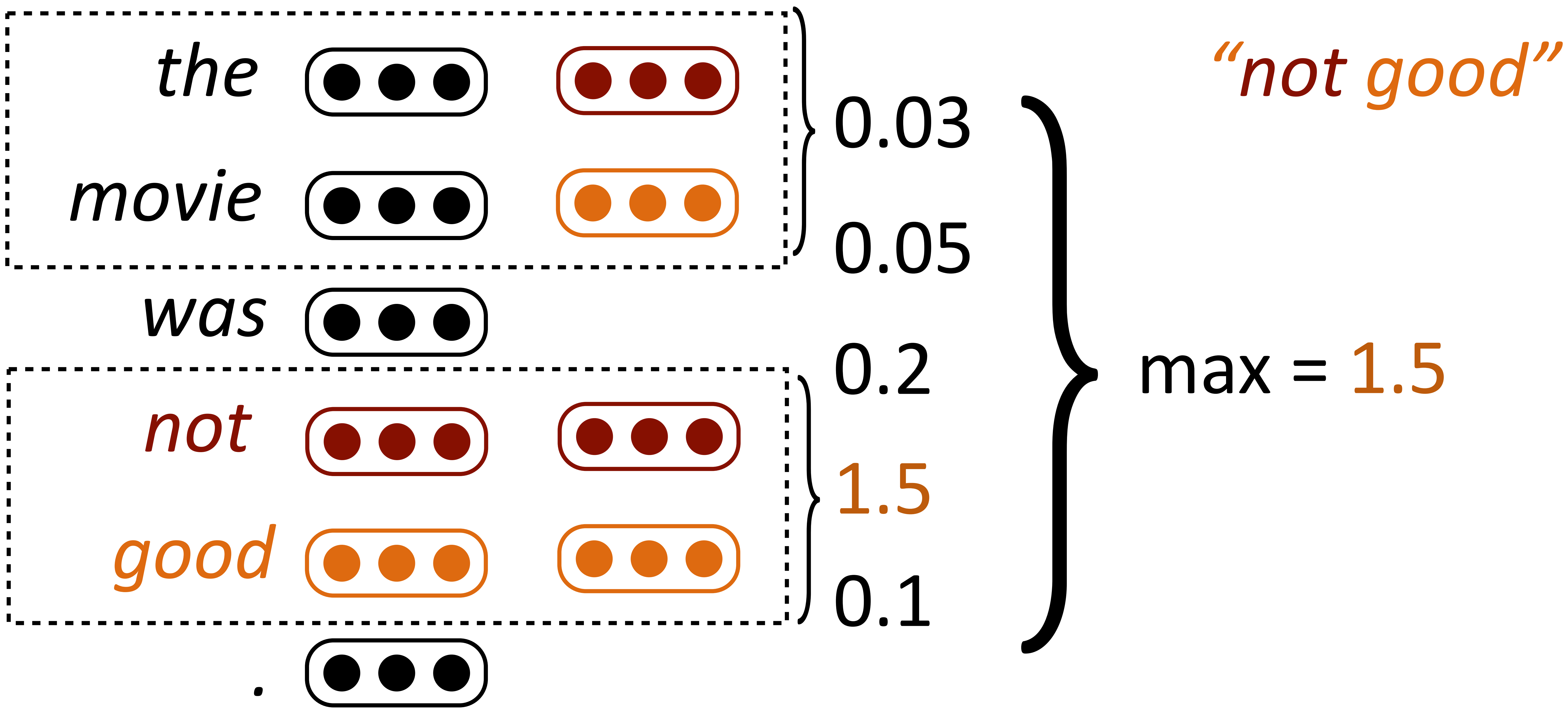

- Analogous to bigram features in bag-of-words models

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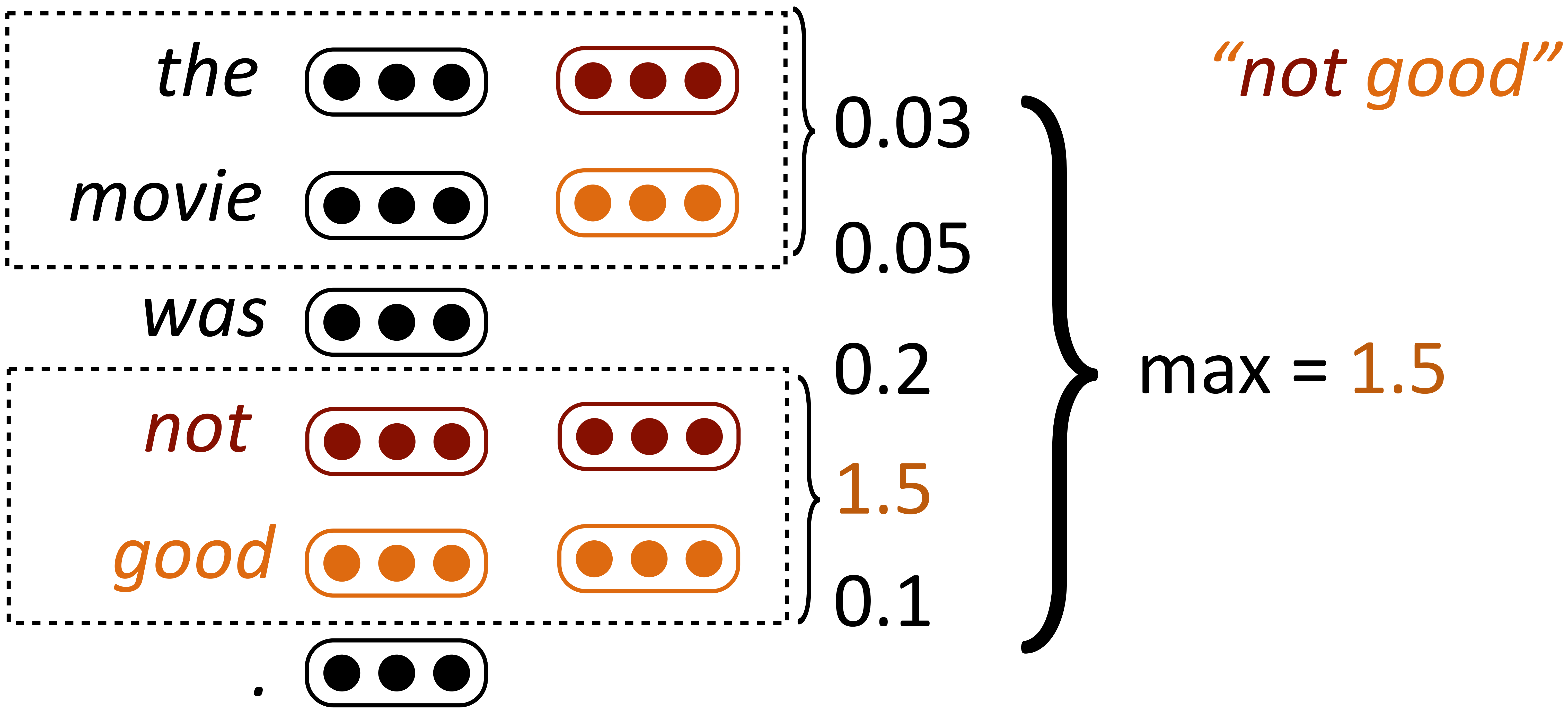


- Analogous to bigram features in bag-of-words models
- Indicator feature of text containing bigram <-> max pooling of a filter that matches that bigram

What can CNNs learn?

the movie was not good

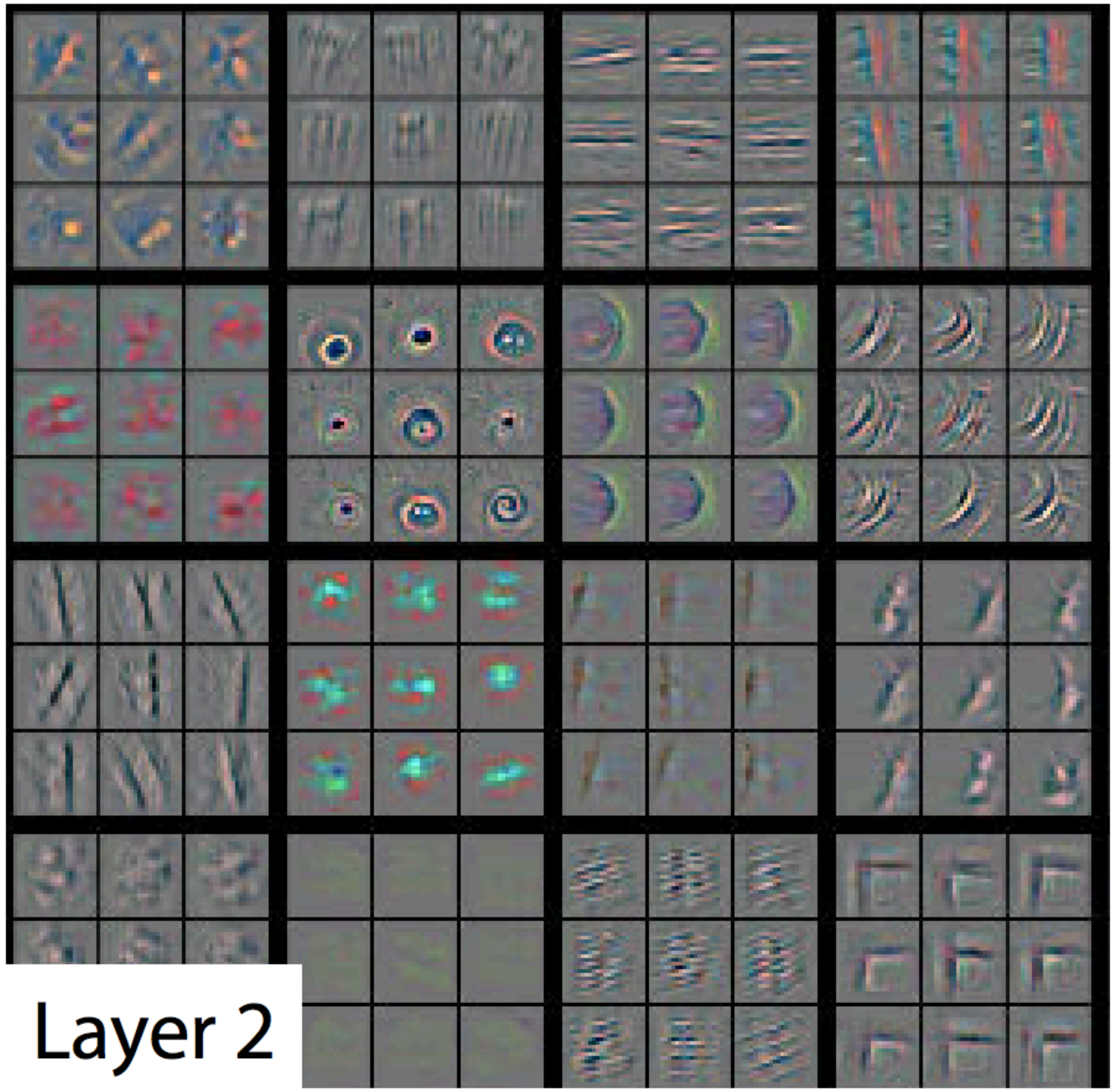
the movie was not really all that good

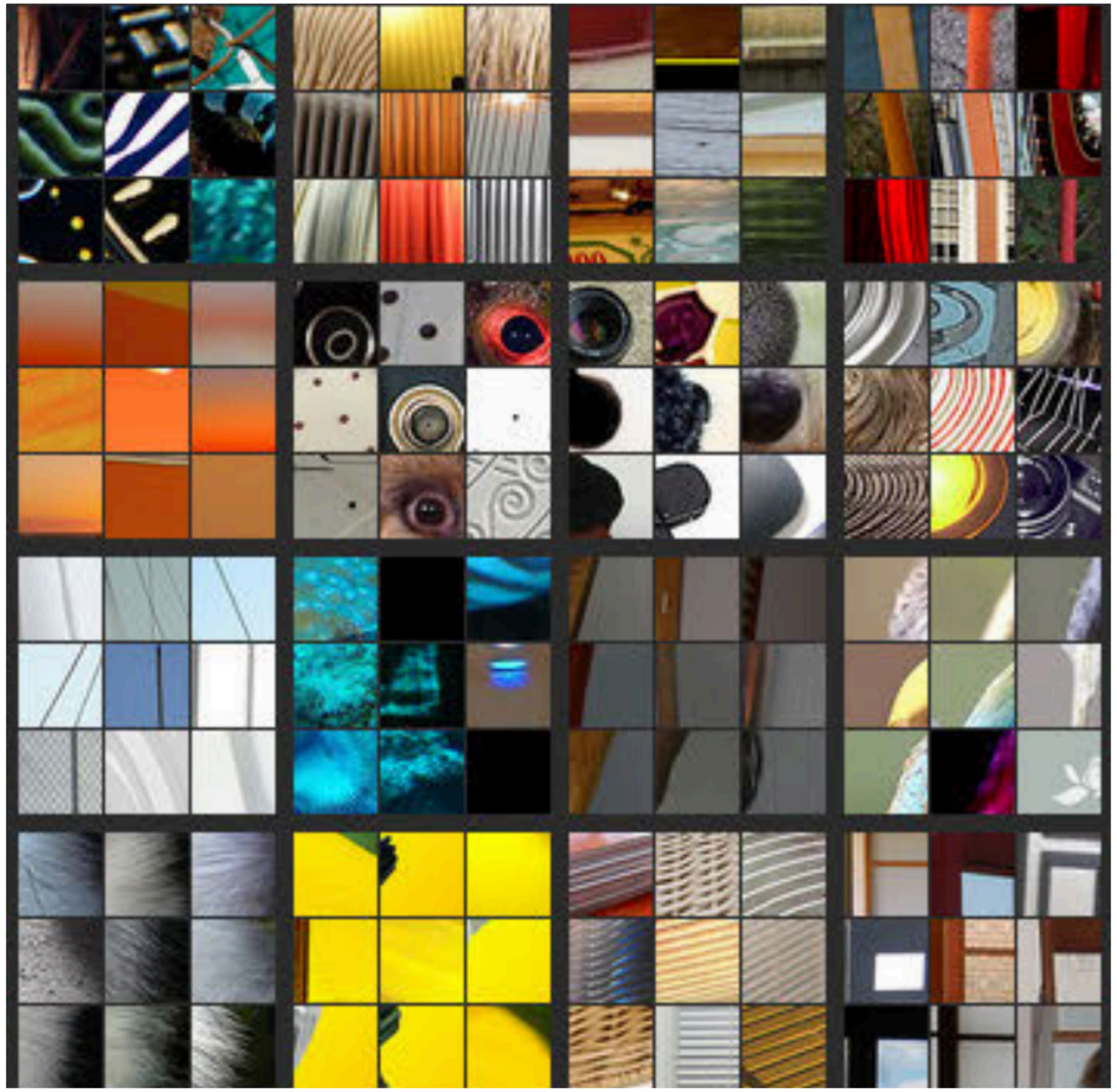
the cinematography was good, the music great, but the movie was bad

I entered the theater in the bloom of youth and left as an old man

Deep Convolutional Networks

- Low-level filters: extract low-level features from the data

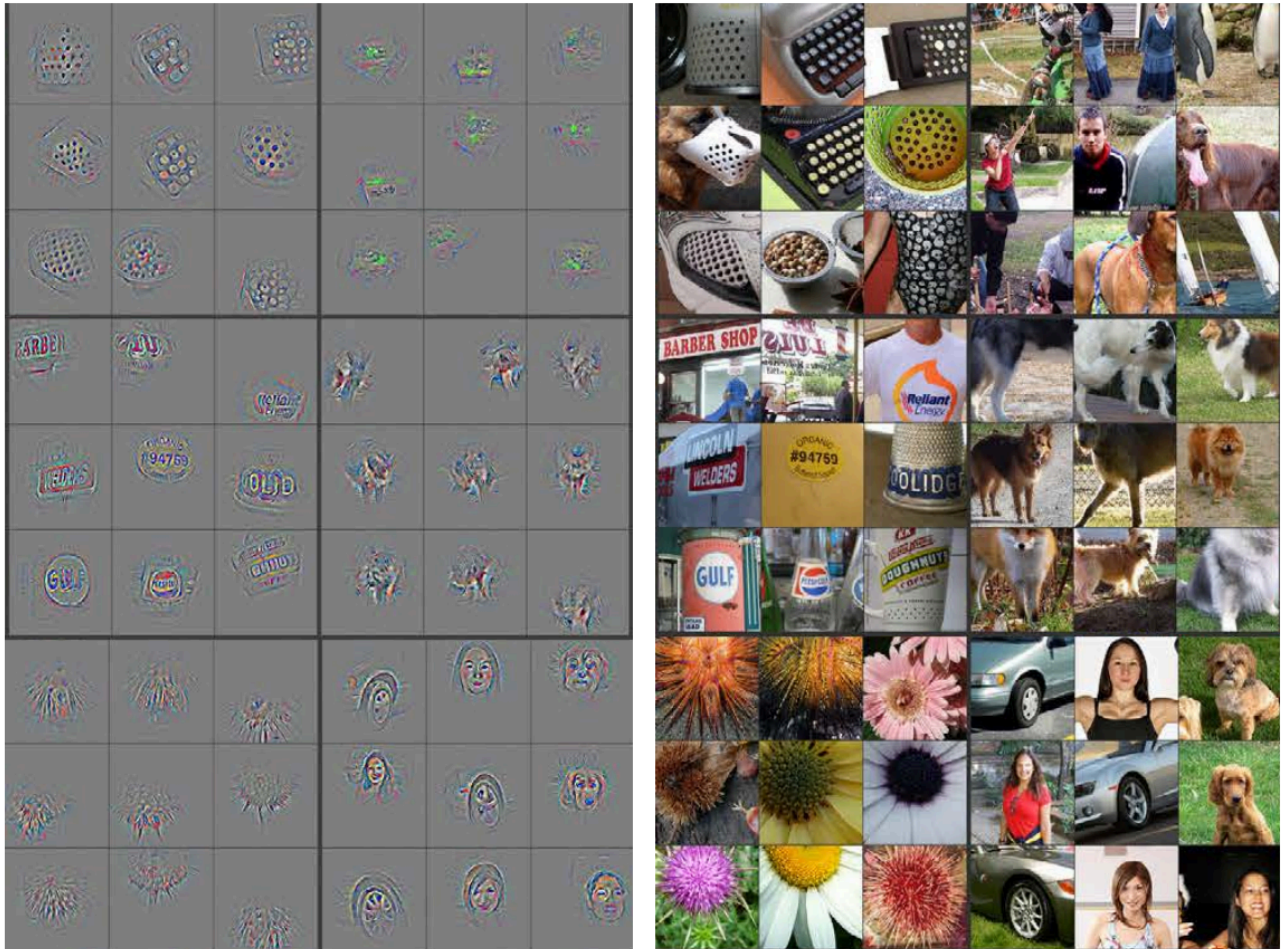




Zeiler and Fergus (2014)

Deep Convolutional Networks

- High-level filters: match larger and more “semantic patterns”



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CNNs: Implementation

- Input is batch_size x n x k matrix, filters are c x m x k matrix (c filters)

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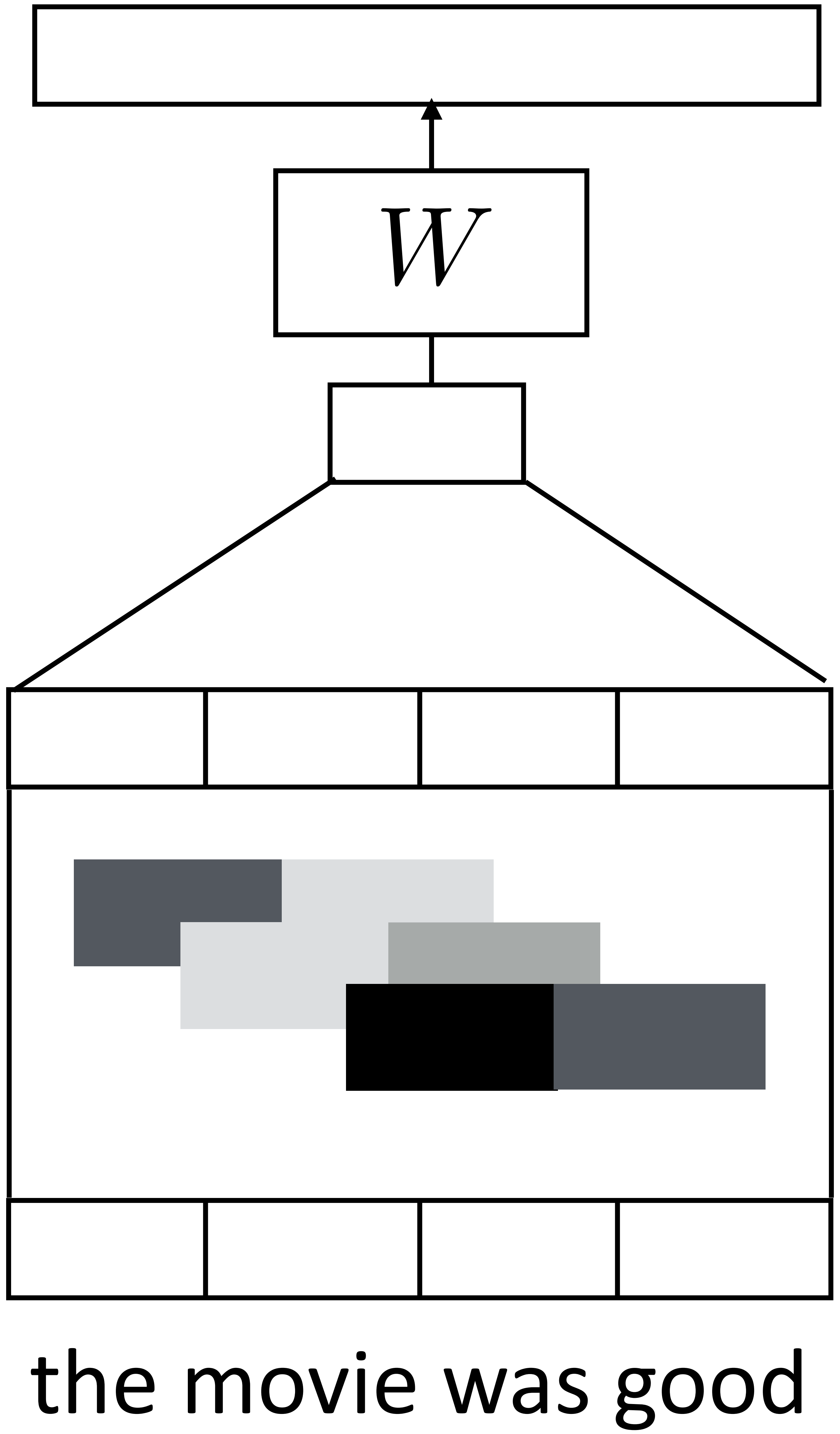
- Input is batch_size x n x k matrix, filters are c x m x k matrix (c filters)
- Typically use filters with m ranging from 1 to 5 or so (multiple filter widths in a single convnet)
- All computation graph libraries support efficient convolution operations

CNNs for Sentence Classification

- Question classification, sentiment, etc.
- Conv+pool, then use feedforward layers to classify
- Can use multiple types of input vectors (fixed initializer and learned)



Kim (2014)

Sentence Classification

Model	MR	SST-1	SST-2	Subj	TREC	CR	MPQA
CNN-multichannel	81.1	47.4	**88.1**	93.2	92.2	**85.0**	89.4
NBSVM (Wang and Manning, 2012)	79.4	–	–	93.2	–	81.8	86.3

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Sentence Classification

movie review
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question type classification

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question type classification

- Also effective at document-level text classification

Kim (2014)

Neural CRF Basics

NER Revisited

Barack	Obama	will	travel	to	Hangzhou	today	for	the	G20	meeting	.
B-PER	I-PER	O	O	O	B-LOC	O	O	O	B-ORG	O	O

Barack Obama (PERSON) *will travel to* *Hangzhou* (LOC) *today for the* *G20* (ORG) *meeting .*

NER Revisited

B-PER	I-PER	O	O	O	B-LOC	O	O	O	B-ORG	O	O
Barack	*Obama*	*will*	*travel*	*to*	*Hangzhou*	*today*	*for*	*the*	*G20*	*meeting*	*.*

PERSON LOC ORG

- Features in CRFs: I[tag=B-LOC & curr_word=*Hangzhou*], I[tag=B-LOC & prev_word=*to*], I[tag=B-LOC & curr_prefix=*Han*]

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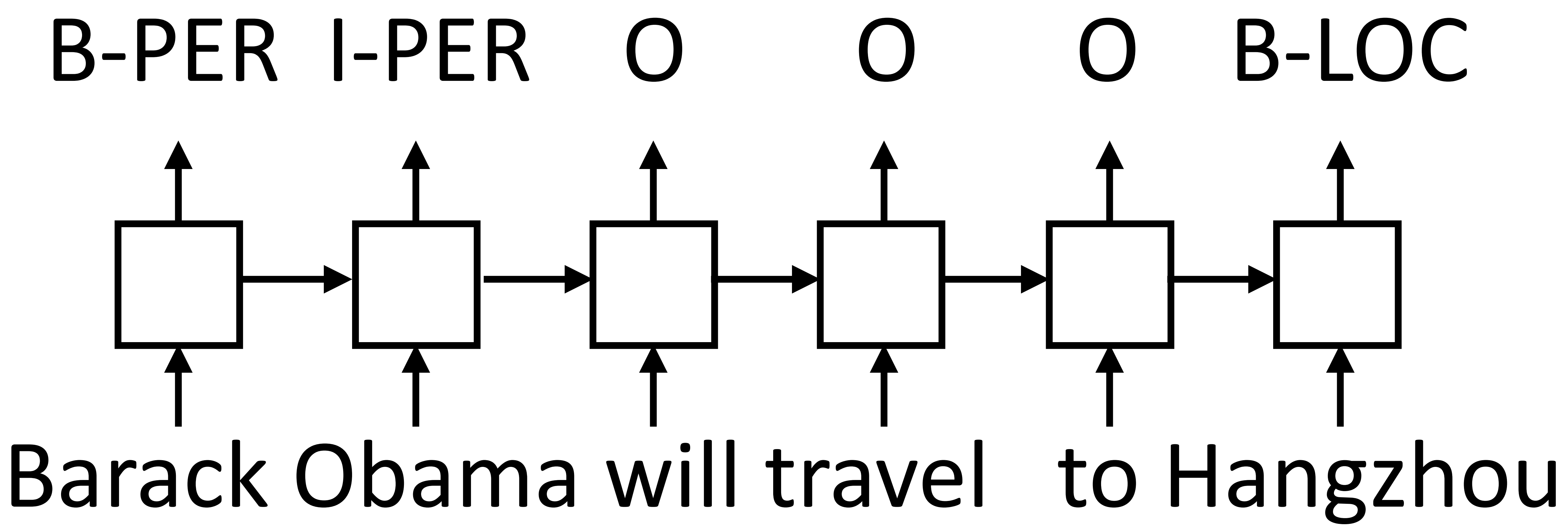
- Linear model over features
- Downsides:
  - Lexical features mean that words need to be seen in the training data
  - Linear model can't capture feature conjunctions as effectively (doesn't work well to look at more than 2 words with a single feature)

LSTMs for NER

B-PER I-PER O O O B-LOC O O O B-ORG O O

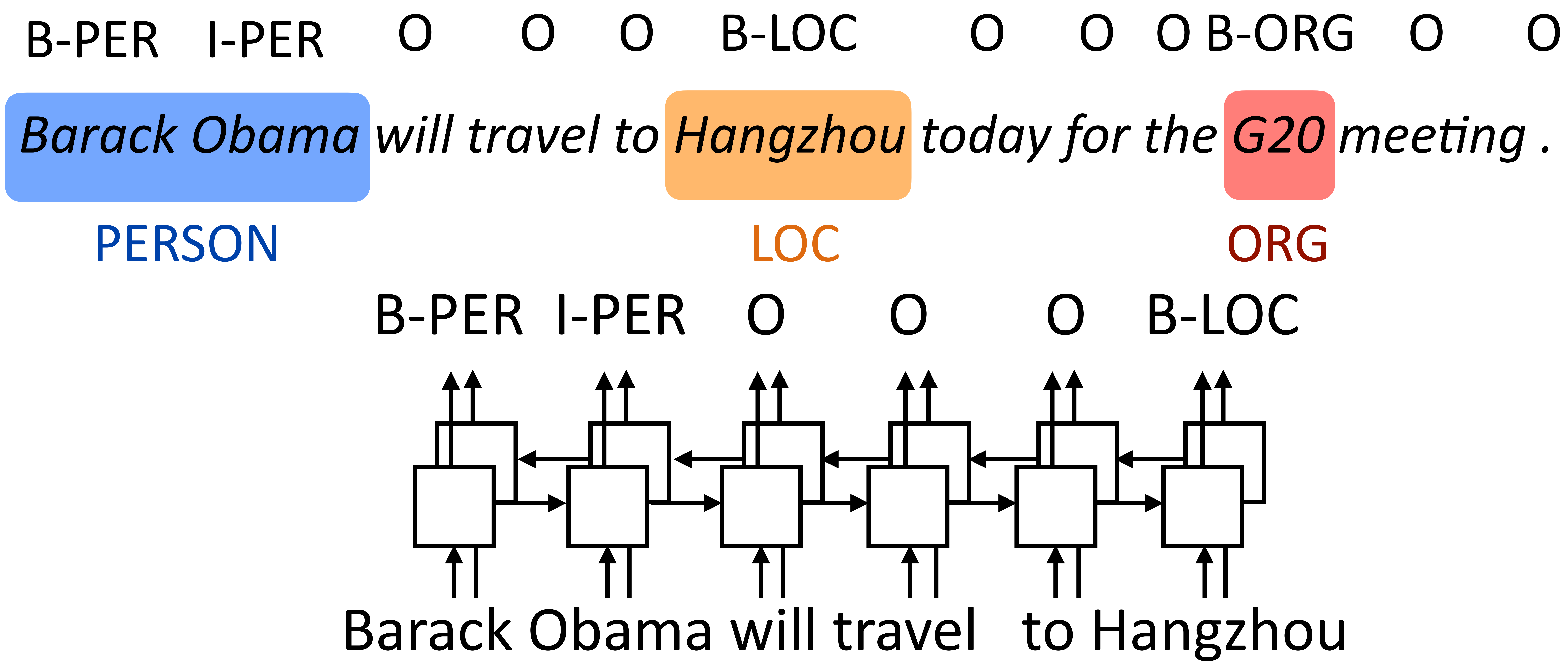
Barack Obama will travel to Hangzhou today for the G20 meeting .

PERSON LOC ORG



- Transducer (LM-like model)
- What are the strengths and weaknesses of this model compared to CRFs?

LSTMs for NER



- Bidirectional transducer model
- What are the strengths and weaknesses of this model compared to CRFs?

Neural CRFs

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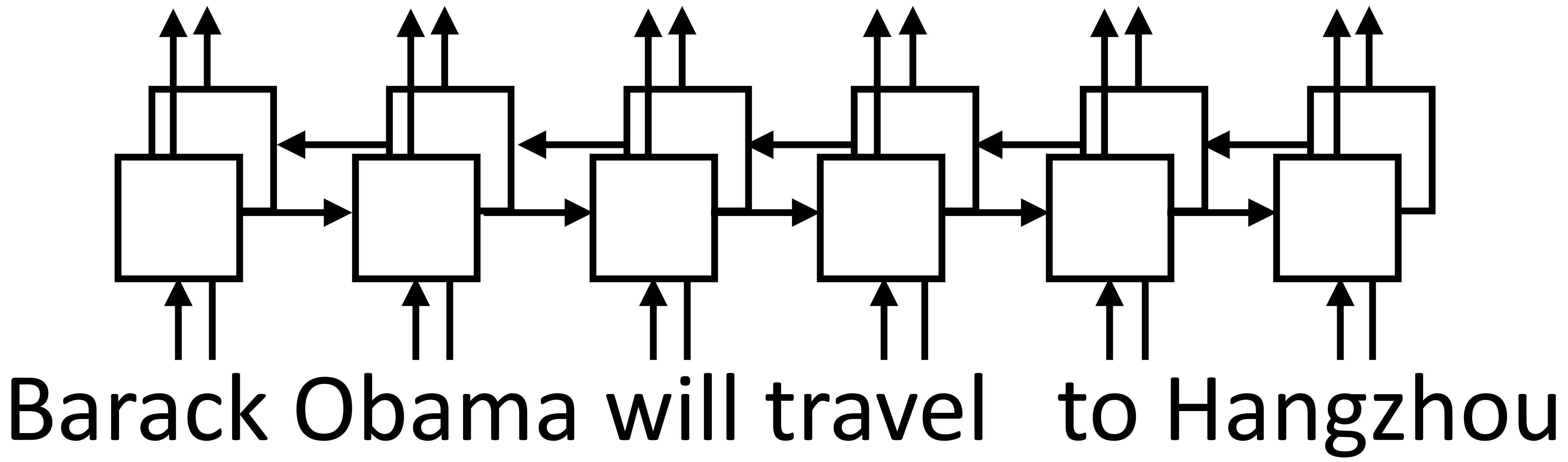

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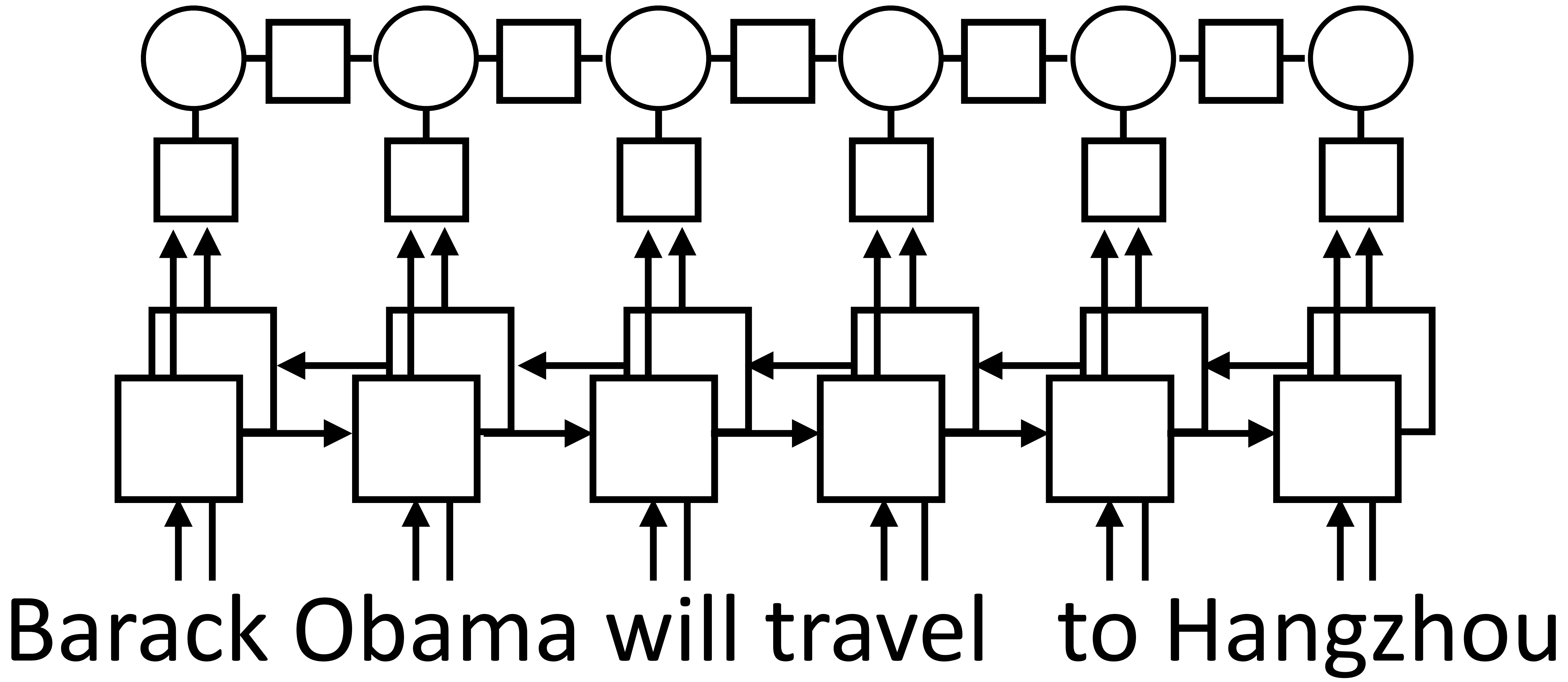

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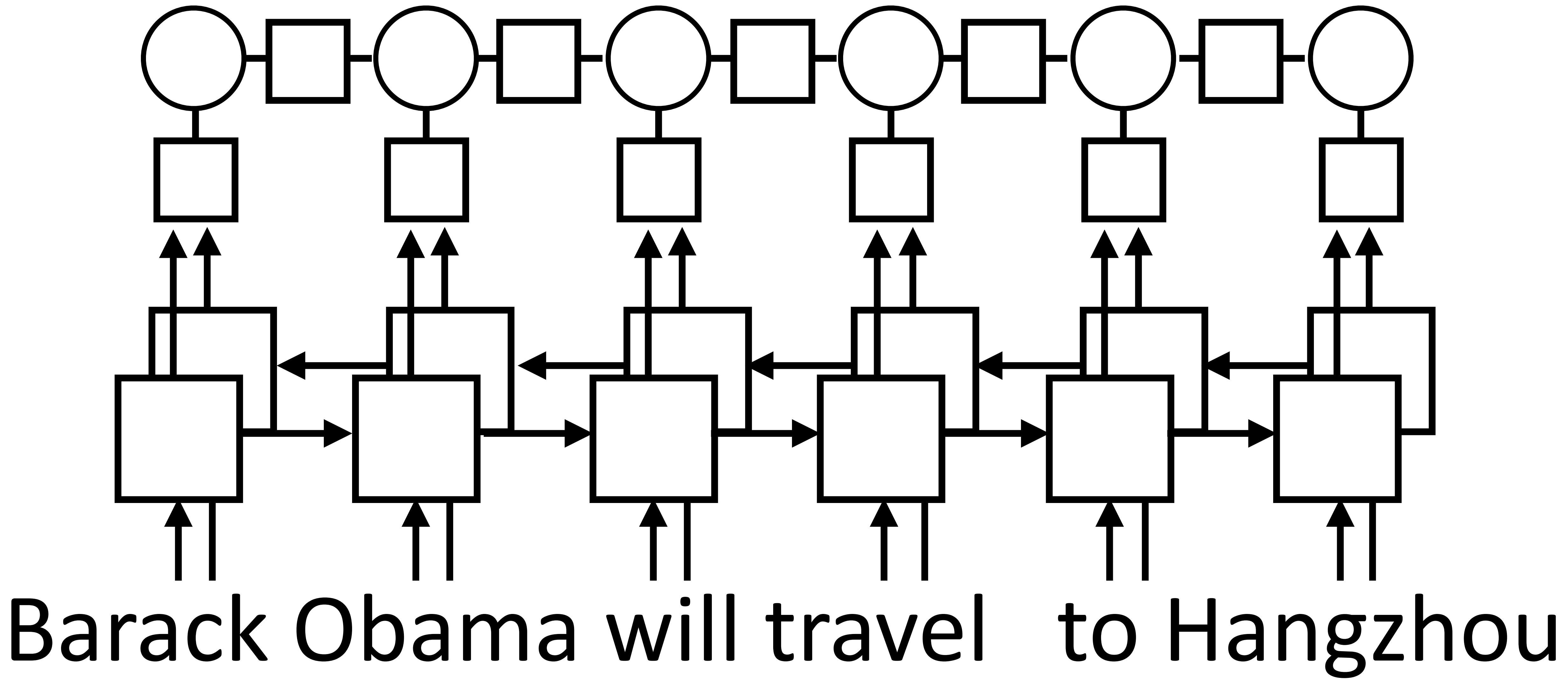
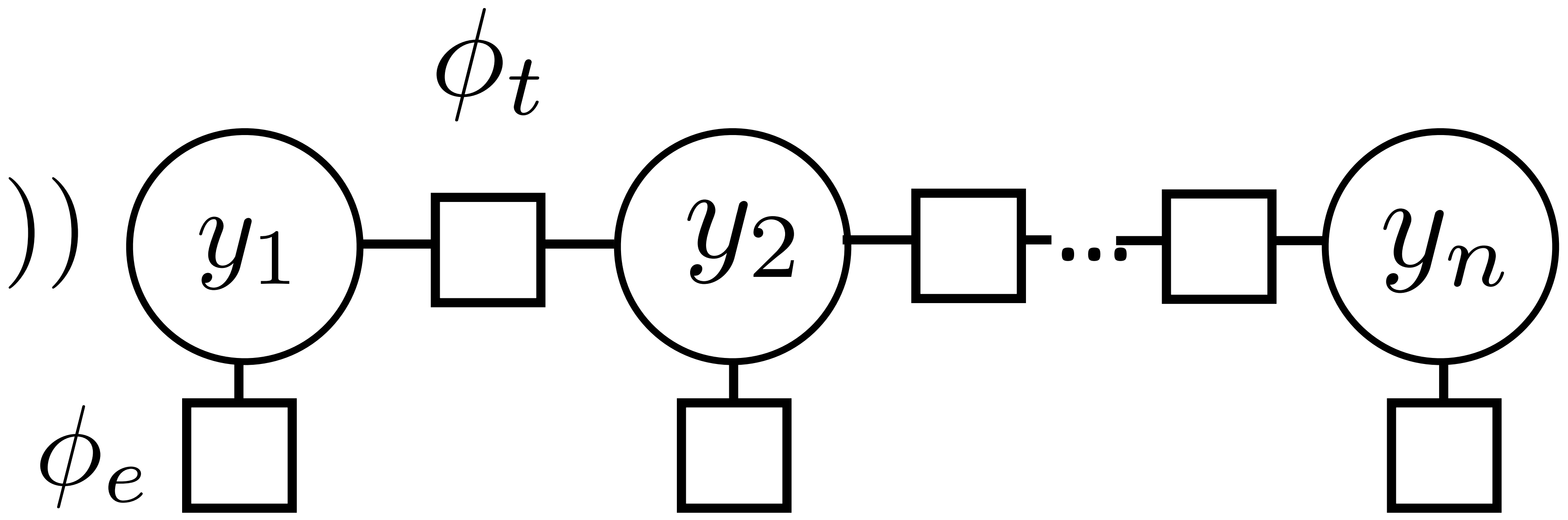


- Neural CRFs: bidirectional LSTMs (or some NN) compute emission potentials, capture structural constraints in transition potentials

Neural CRFs

$$P(\mathbf{y}|\mathbf{x}) = \frac{1}{Z}\prod_{i=2}^{n}\exp(\phi_t(y_{i-1}, y_i))\prod_{i=1}^{n}\exp(\phi_e(y_i, i, \mathbf{x}))$$



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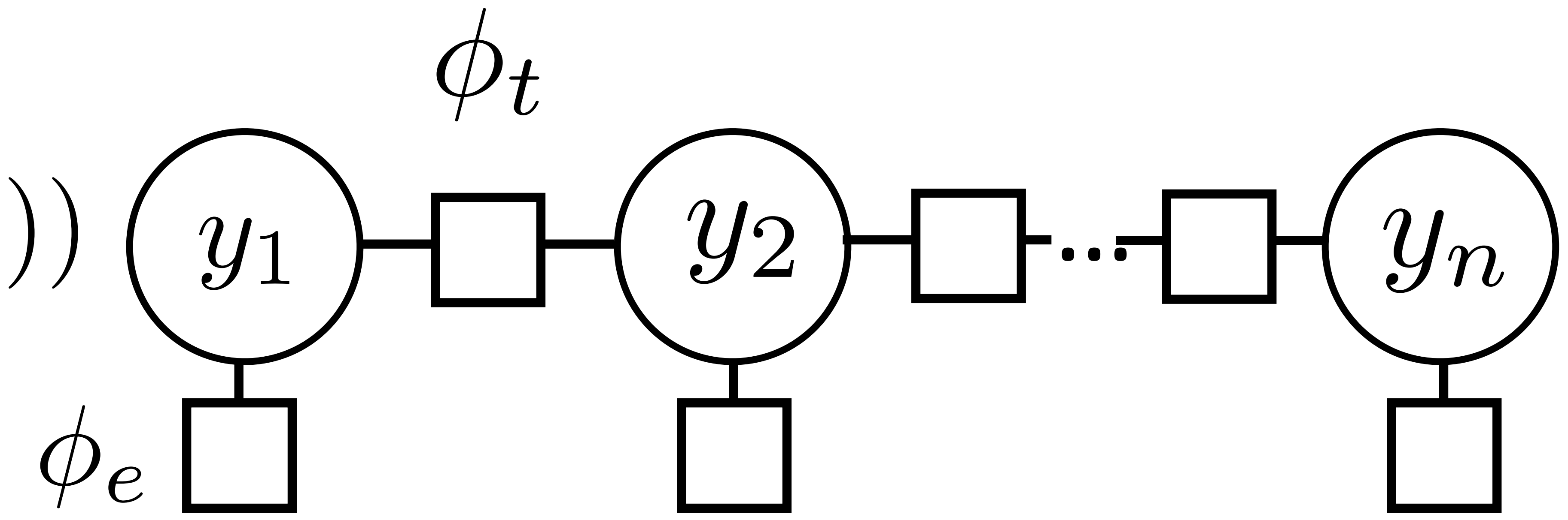

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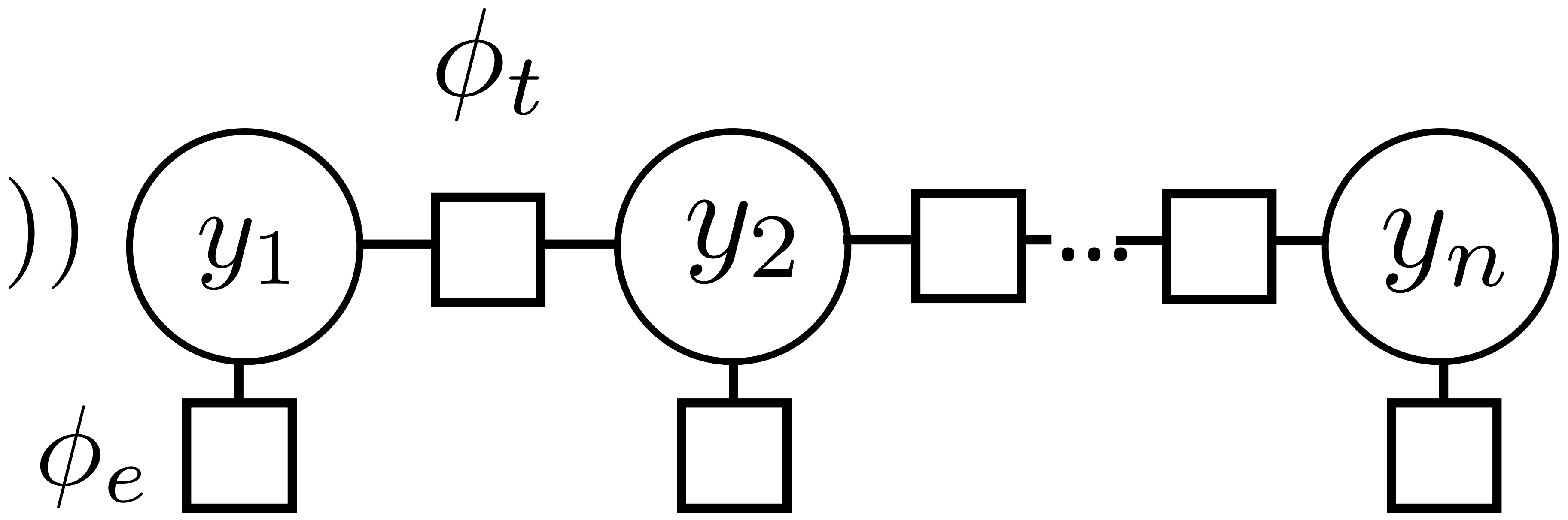

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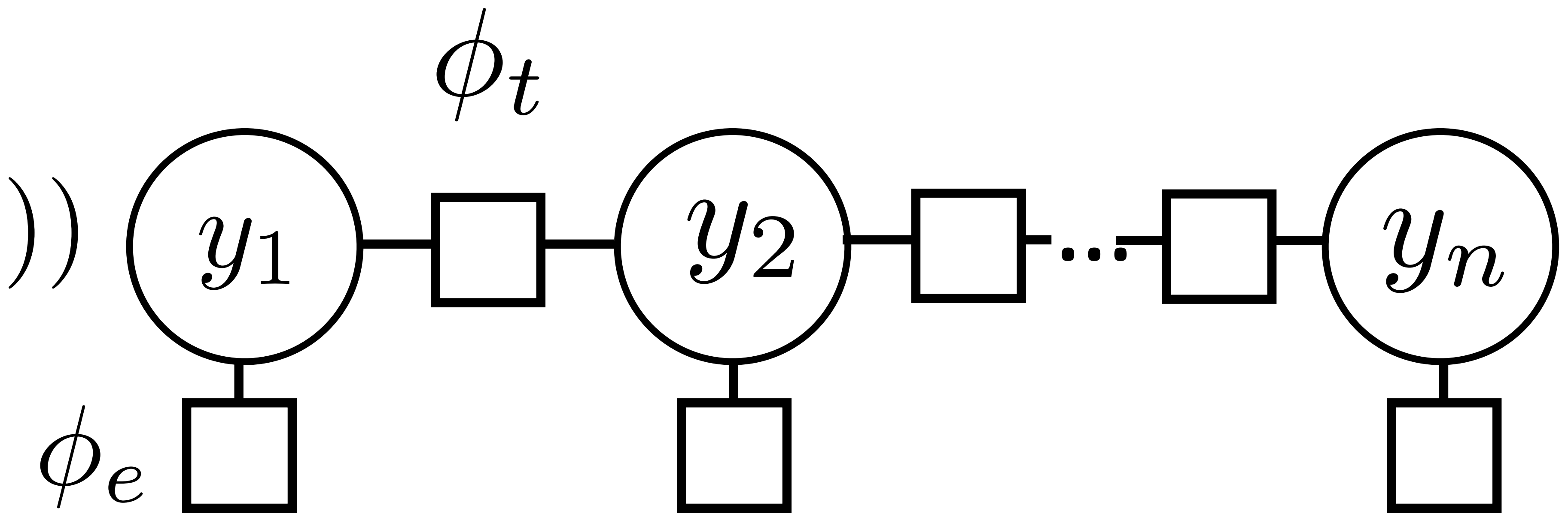

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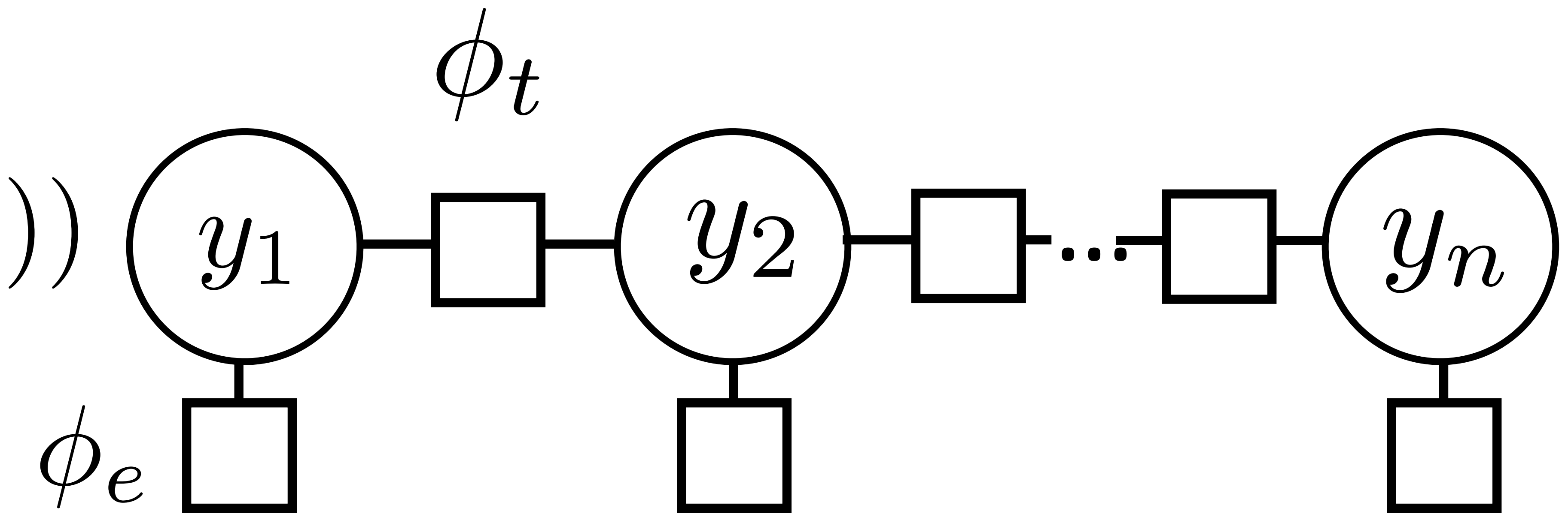

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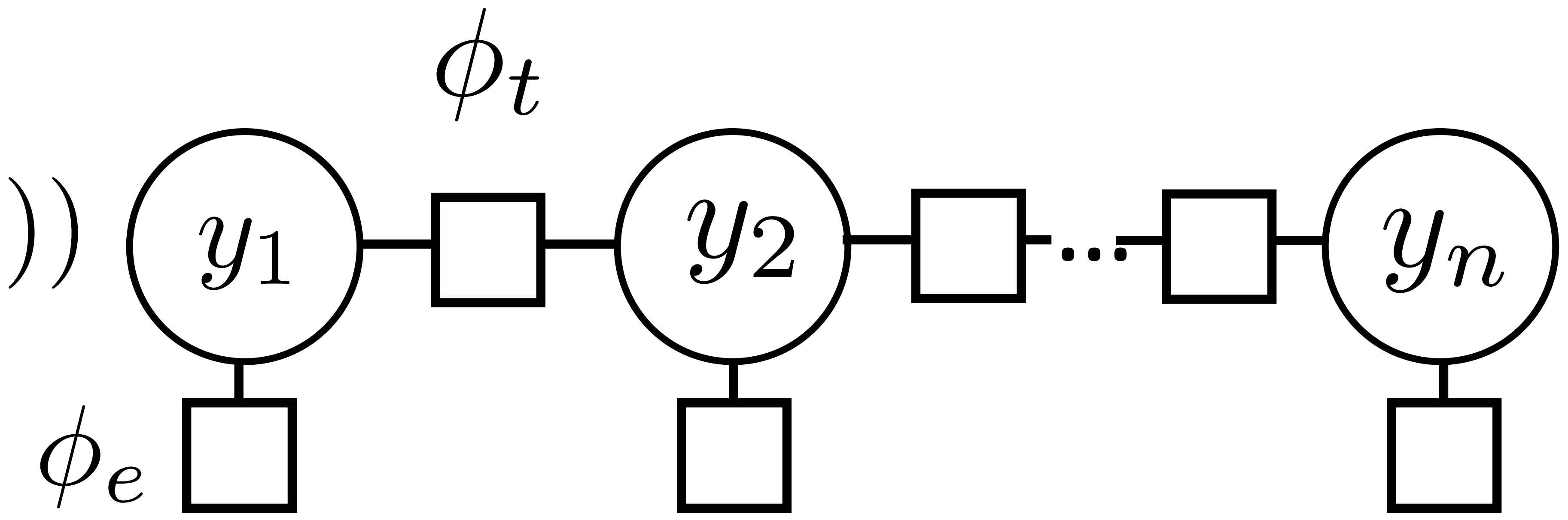
- Neural network computes unnormalized potentials that are consumed and “normalized” by a structured model
- Inference: compute *f*, use Viterbi

Computing Gradients

$$P(\mathbf{y}|\mathbf{x}) = \frac{1}{Z}\prod_{i=2}^{n}\exp(\phi_t(y_{i-1}, y_i))\prod_{i=1}^{n}\exp(\phi_e(y_i, i, \mathbf{x}))$$



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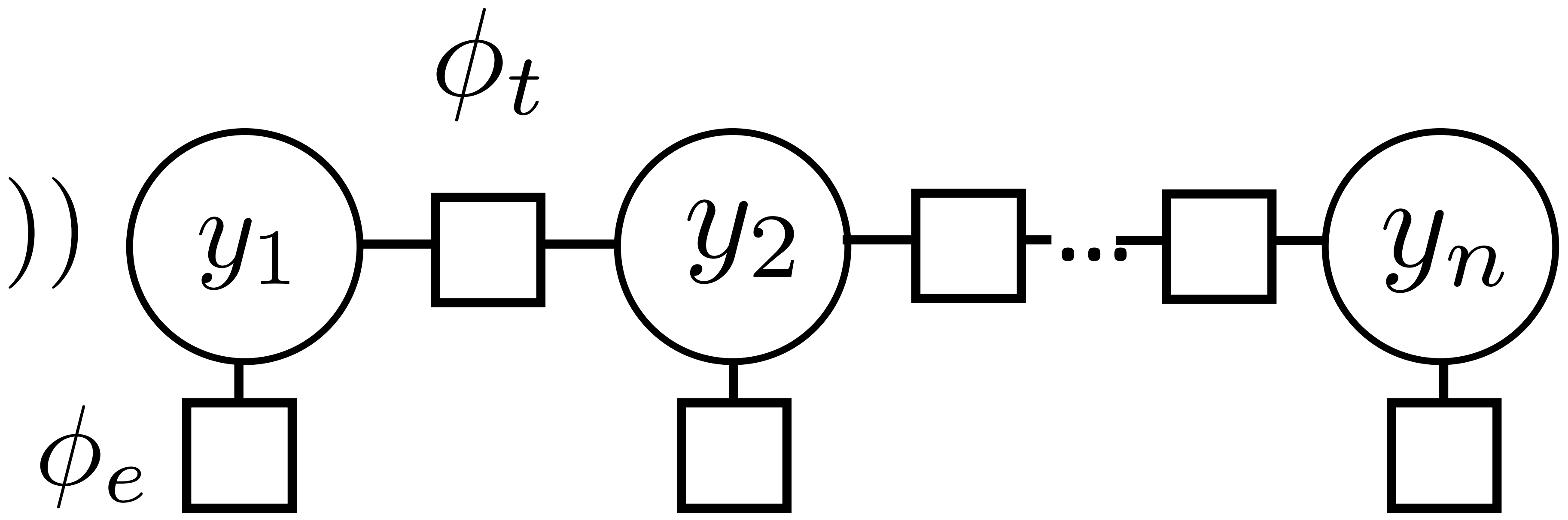

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$$\frac{\partial \mathcal{L}}{\partial \phi_{e,i}} = -P(y_i = s|\mathbf{x}) + I[s \text{ is gold}]$$ “error signal”, compute with F-B

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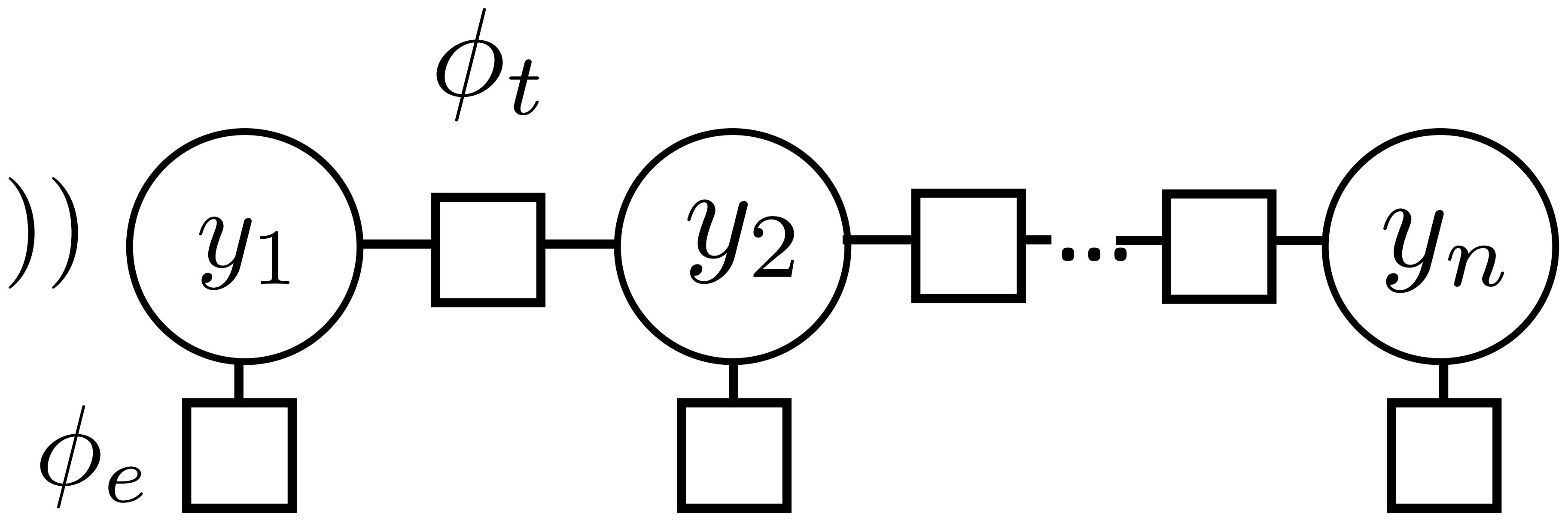

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- For linear model: $\frac{\partial \phi_{e,i}}{w_i} = f_{e,i}(y_i, i, \mathbf{x})$

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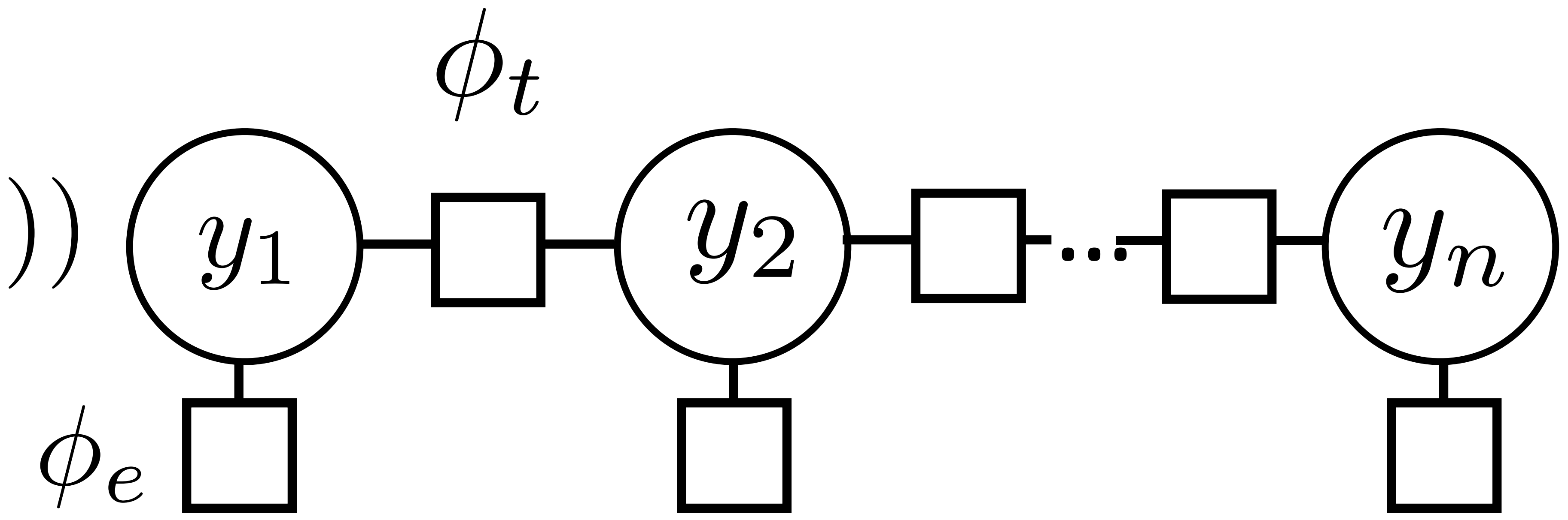

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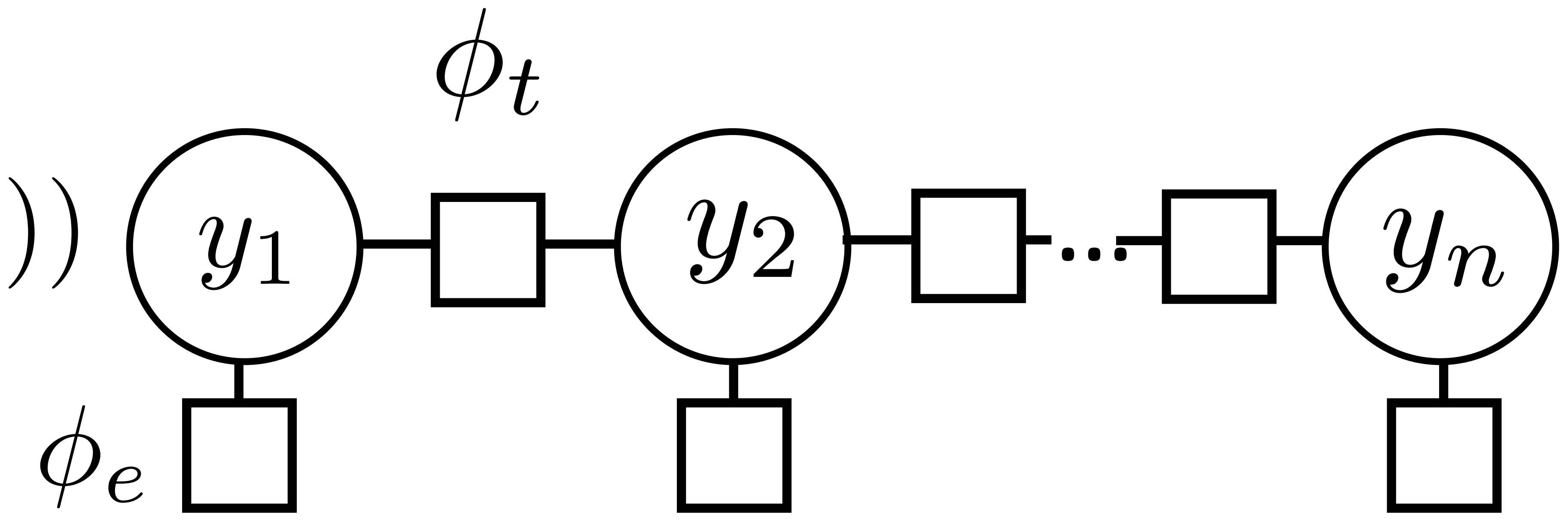

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chain rule say to multiply together, gives our update

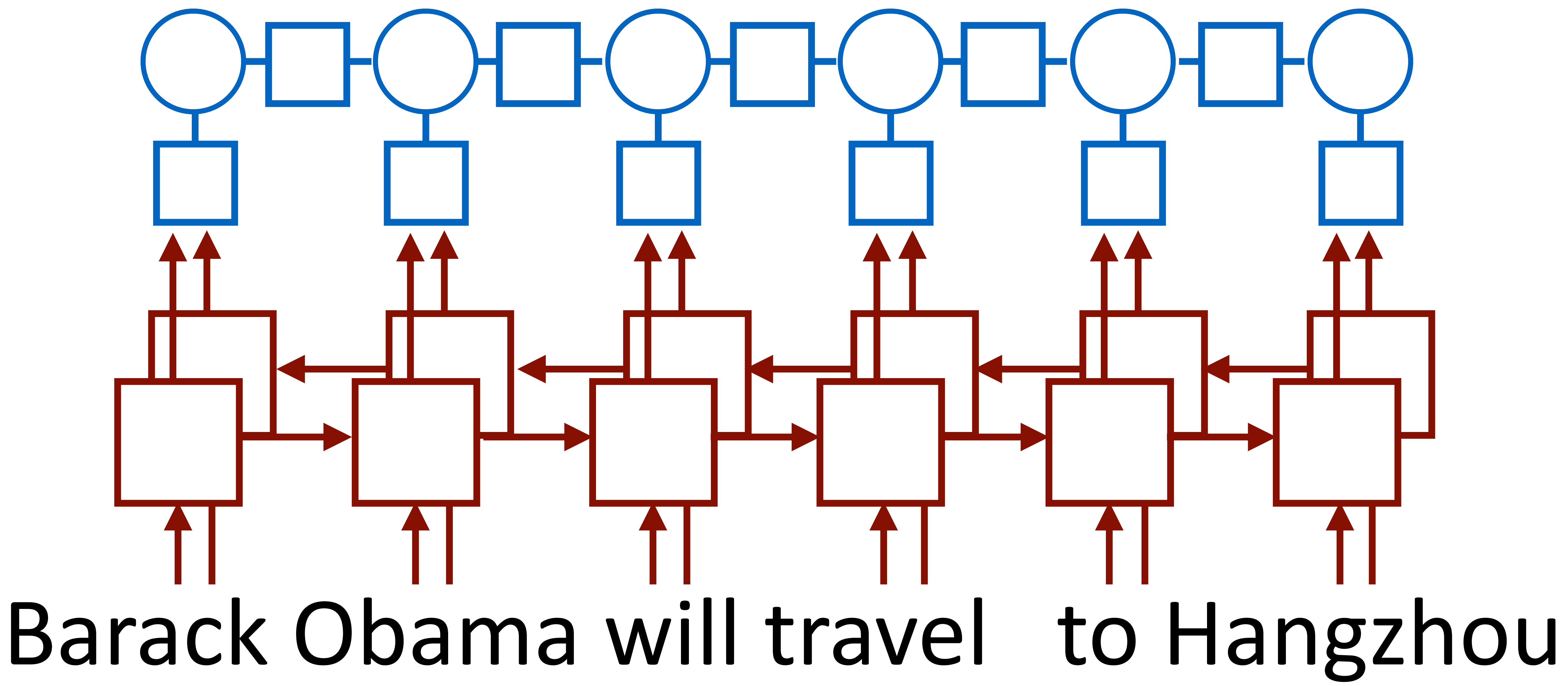
- For linear model: $\frac{\partial \phi_{e,i}}{w_i} = f_{e,i}(y_i, i, \mathbf{x})$
- For neural model: compute gradient of phi w.r.t. parameters of neural net

Neural CRFs

B-PER I-PER O O O B-LOC O O O B-ORG O O

Barack Obama will travel to Hangzhou today for the G20 meeting .

PERSON LOC ORG



Neural CRFs

B-PER	I-PER	O	O	O	B-LOC	O	O	O	B-ORG	O	O
Barack	*Obama*	*will*	*travel*	*to*	*Hangzhou*	*today*	*for*	*the*	*G20*	*meeting*	*.*

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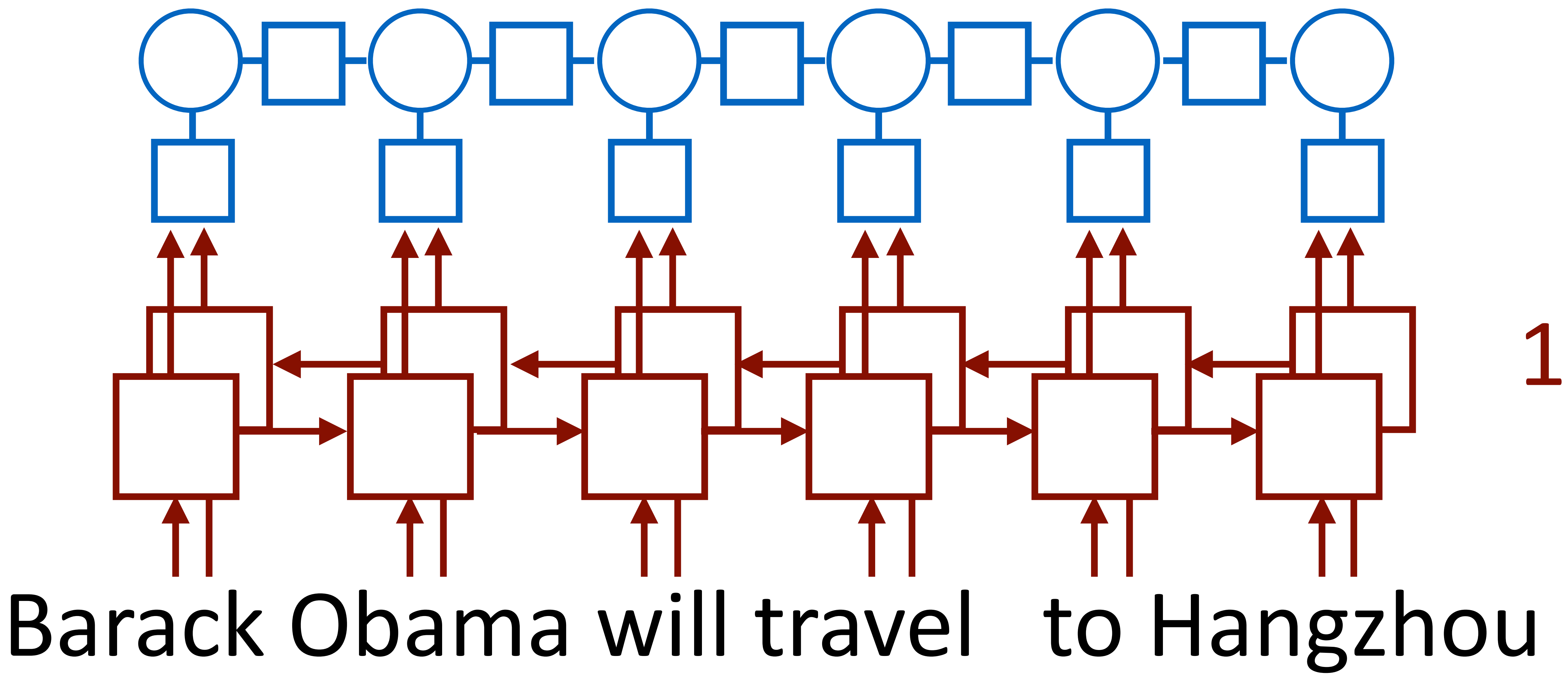

1) Compute f(**x**)

Neural CRFs

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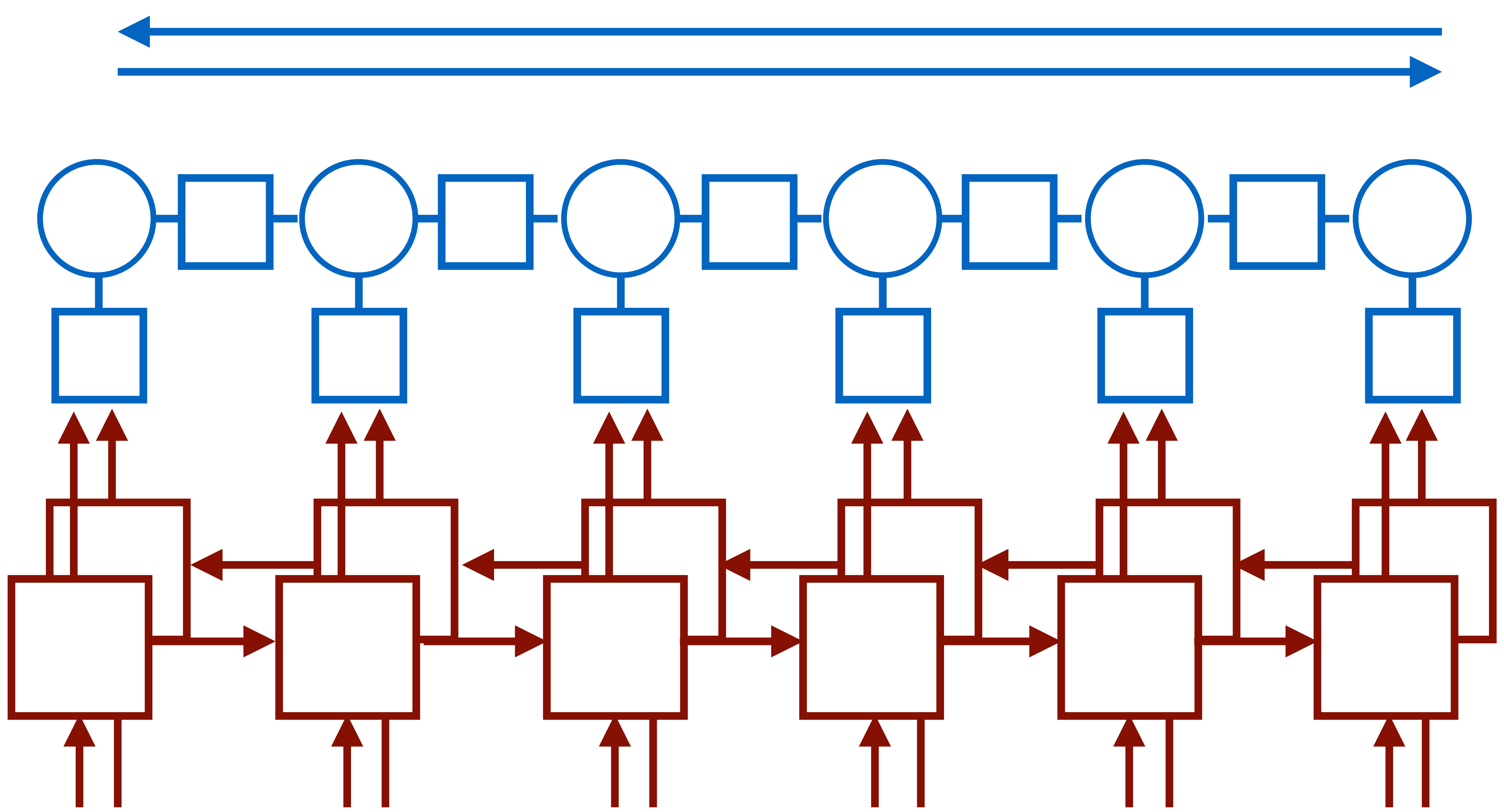

2) Run forward-backward

1) Compute f(**x**)

Barack Obama will travel to Hangzhou

Neural CRFs

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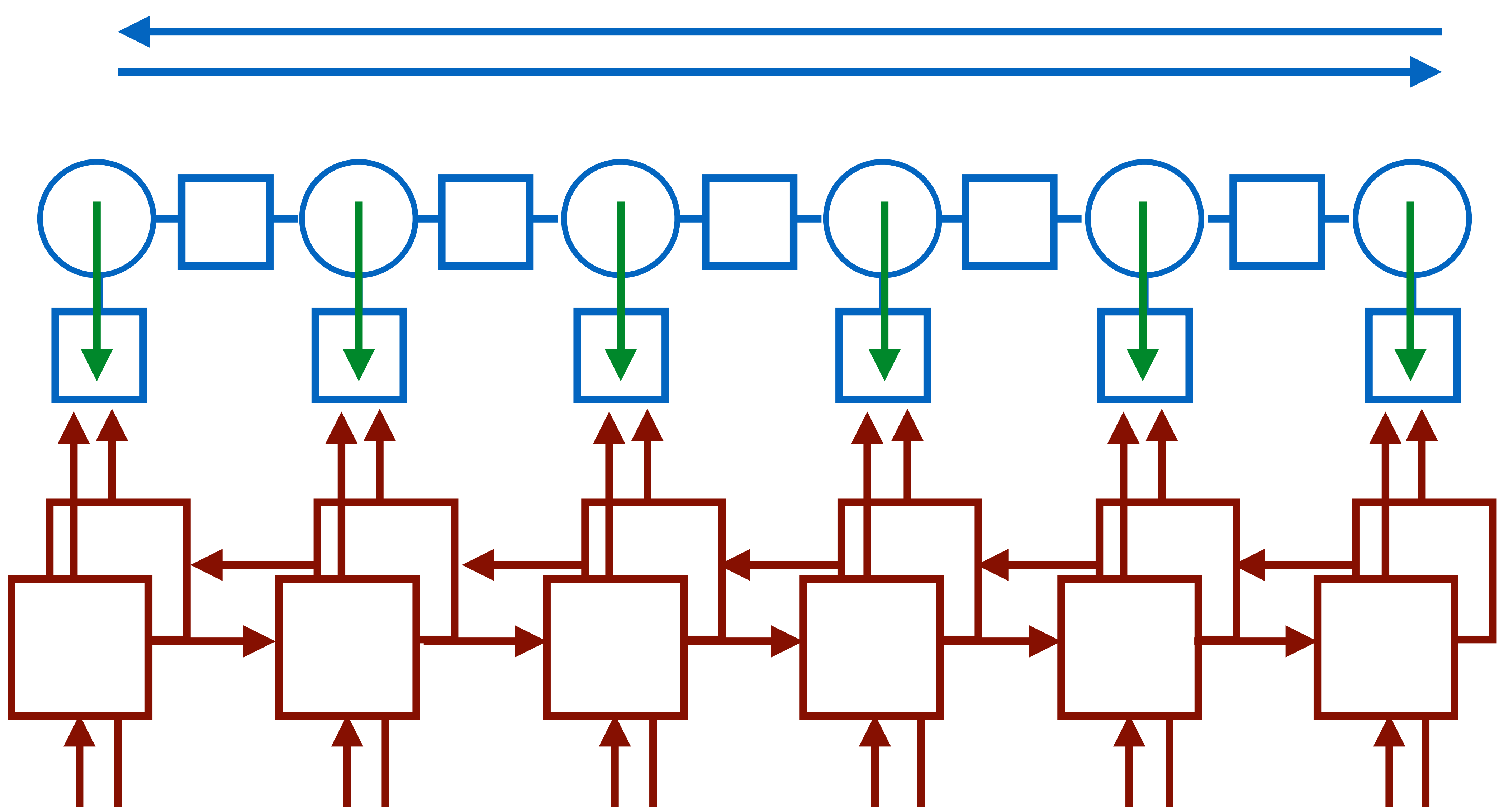


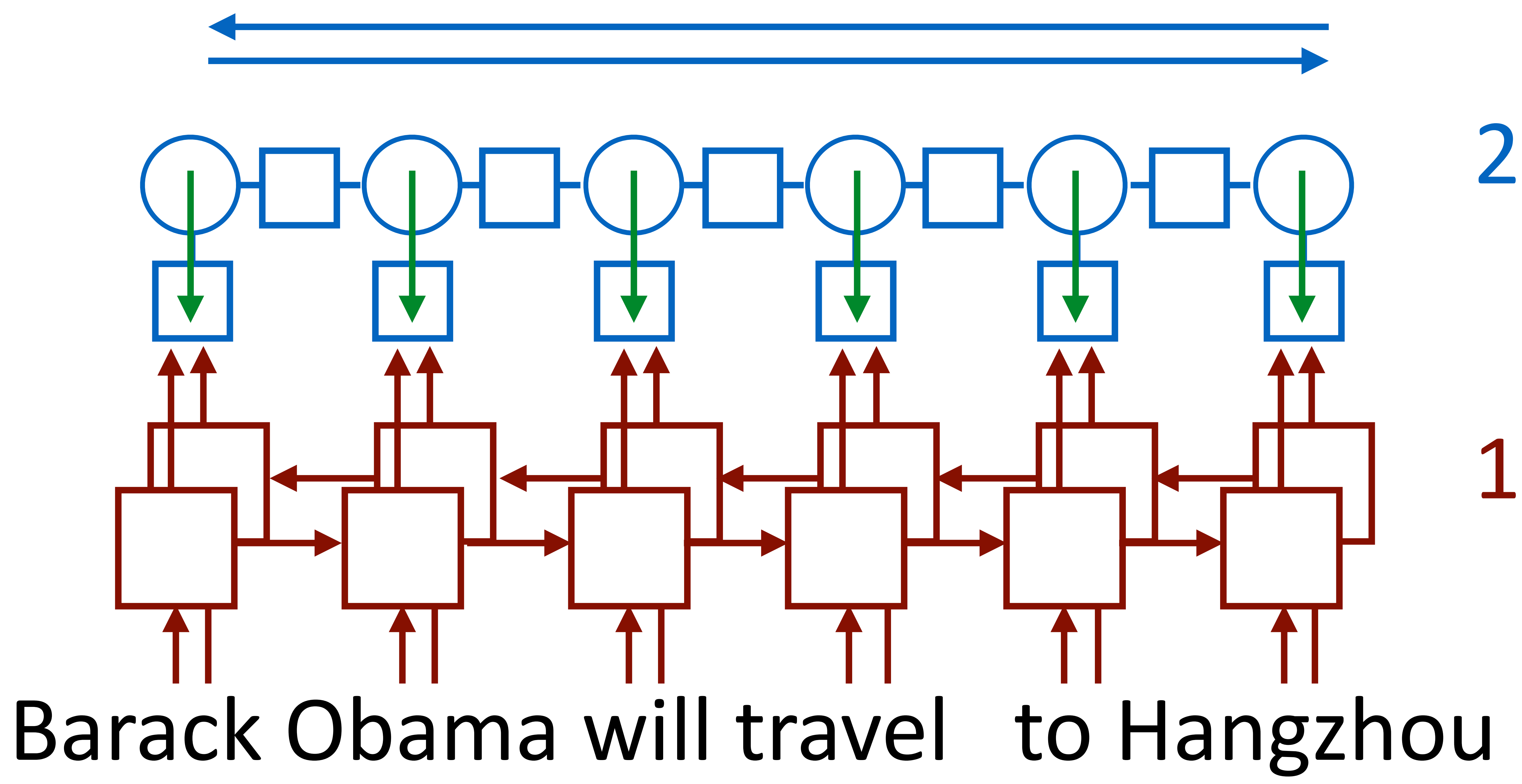
2) Run forward-backward

3) Compute error signal

1) Compute f(**x**)

Barack Obama will travel to Hangzhou

Neural CRFs



2) Run forward-backward

3) Compute error signal

1) Compute f(**x**)

4) Backprop (no knowledge of sequential structure required)

FFNN Neural CRF for NER

B-PER	I-PER	O	O	O	B-LOC	O	O	O	B-ORG	O	O
Barack	*Obama*	*will*	*travel*	*to*	*Hangzhou*	*today*	*for*	*the*	*G20*	*meeting*	*.*
PERSON					LOC				ORG		

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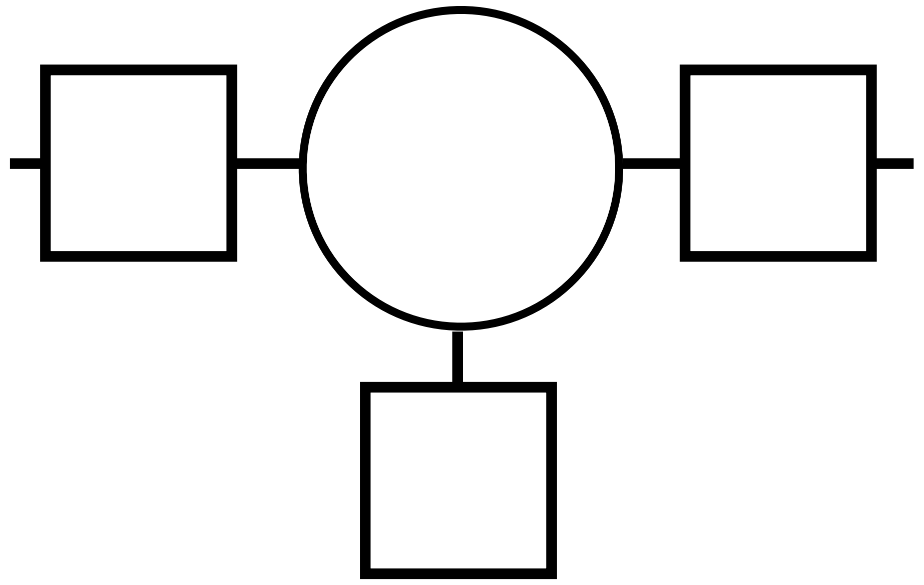
PERSON LOC ORG



to ***Hangzhou*** *today*

FFNN Neural CRF for NER

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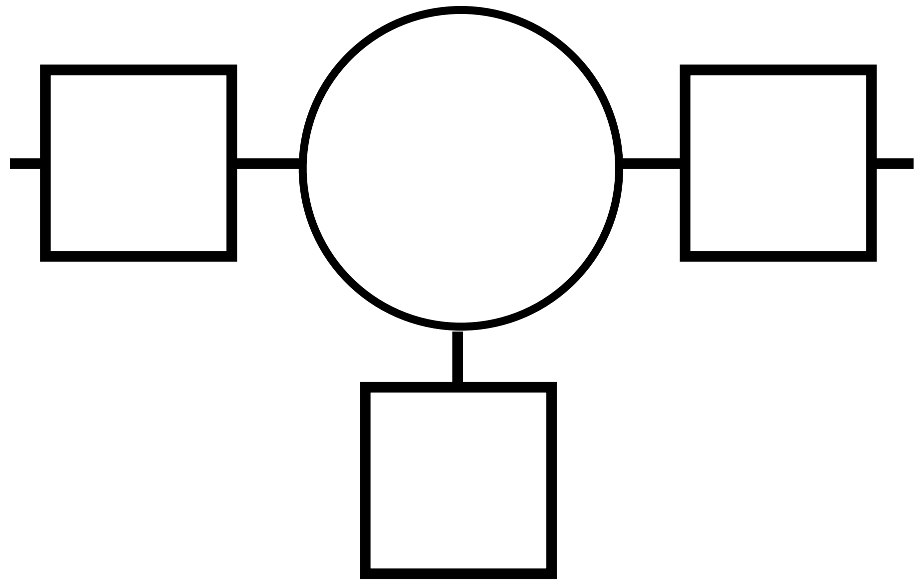


$$f(\mathbf{x}, i) = [\mathrm{emb}(\mathbf{x}_{i-1}), \mathrm{emb}(\mathbf{x}_i), \mathrm{emb}(\mathbf{x}_{i+1})]$$

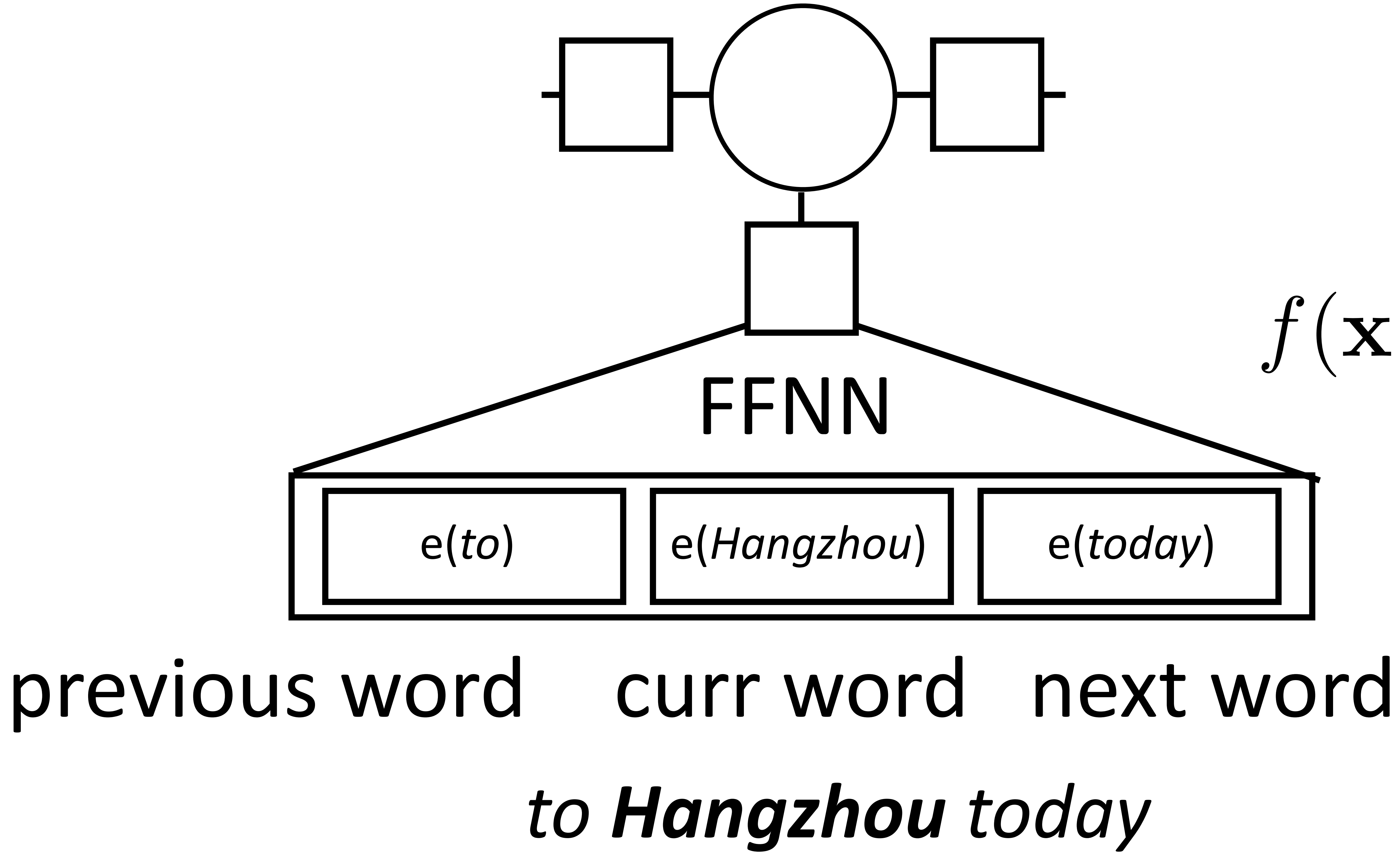
previous word curr word next word

*to **Hangzhou** today*

FFNN Neural CRF for NER

B-PER	I-PER	O	O	O	B-LOC	O	O	O	B-ORG	O	O
Barack	*Obama*	*will*	*travel*	*to*	*Hangzhou*	*today*	*for*	*the*	*G20*	*meeting*	*.*

PERSON (*Barack Obama*) LOC (*Hangzhou*) ORG (*G20*)



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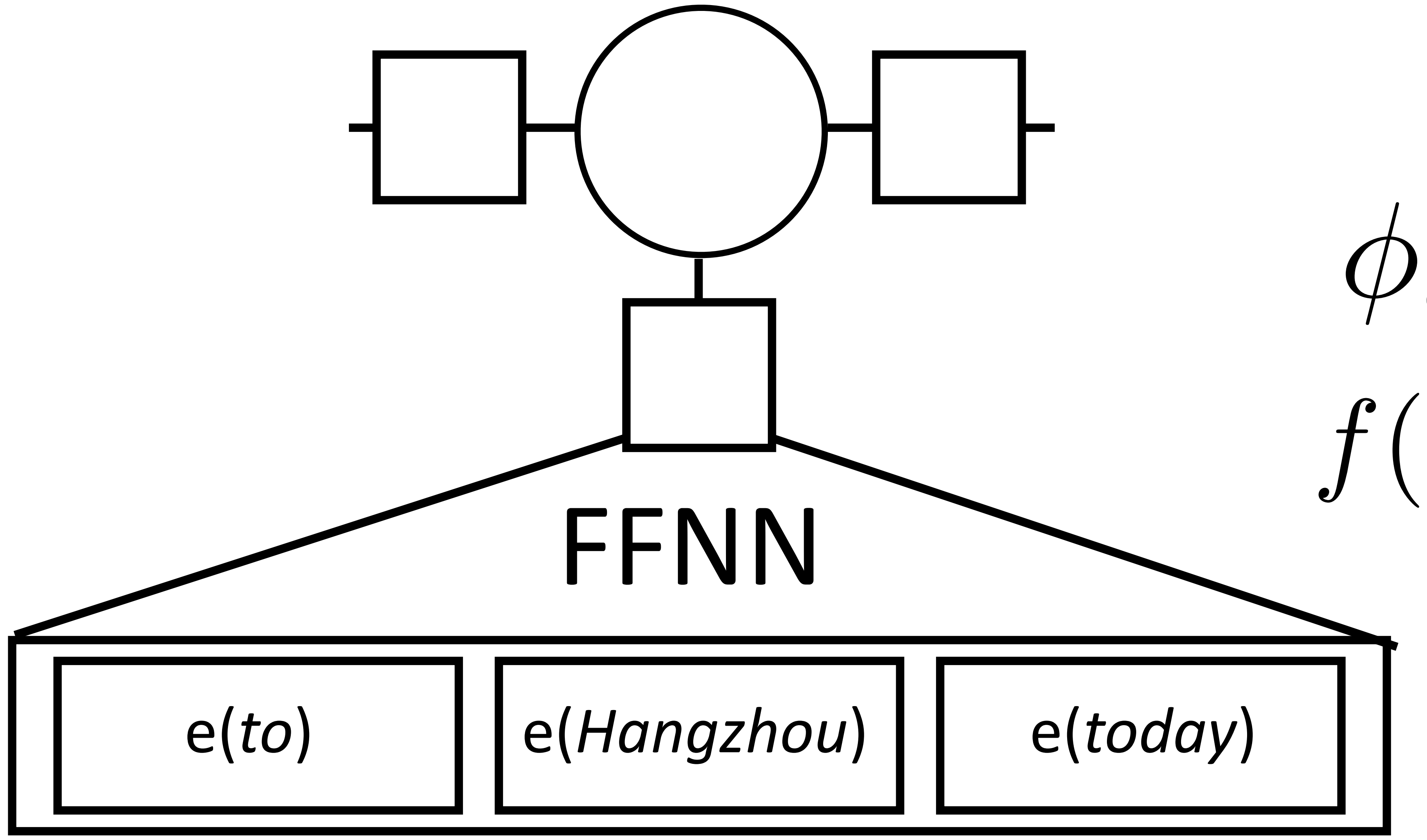

previous word curr word next word

to ***Hangzhou*** *today*

$$\phi_e = W g(V f(\mathbf{x}, i))$$

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LSTM Neural CRFs

B-PER I-PER O O O B-LOC O O O B-ORG O O

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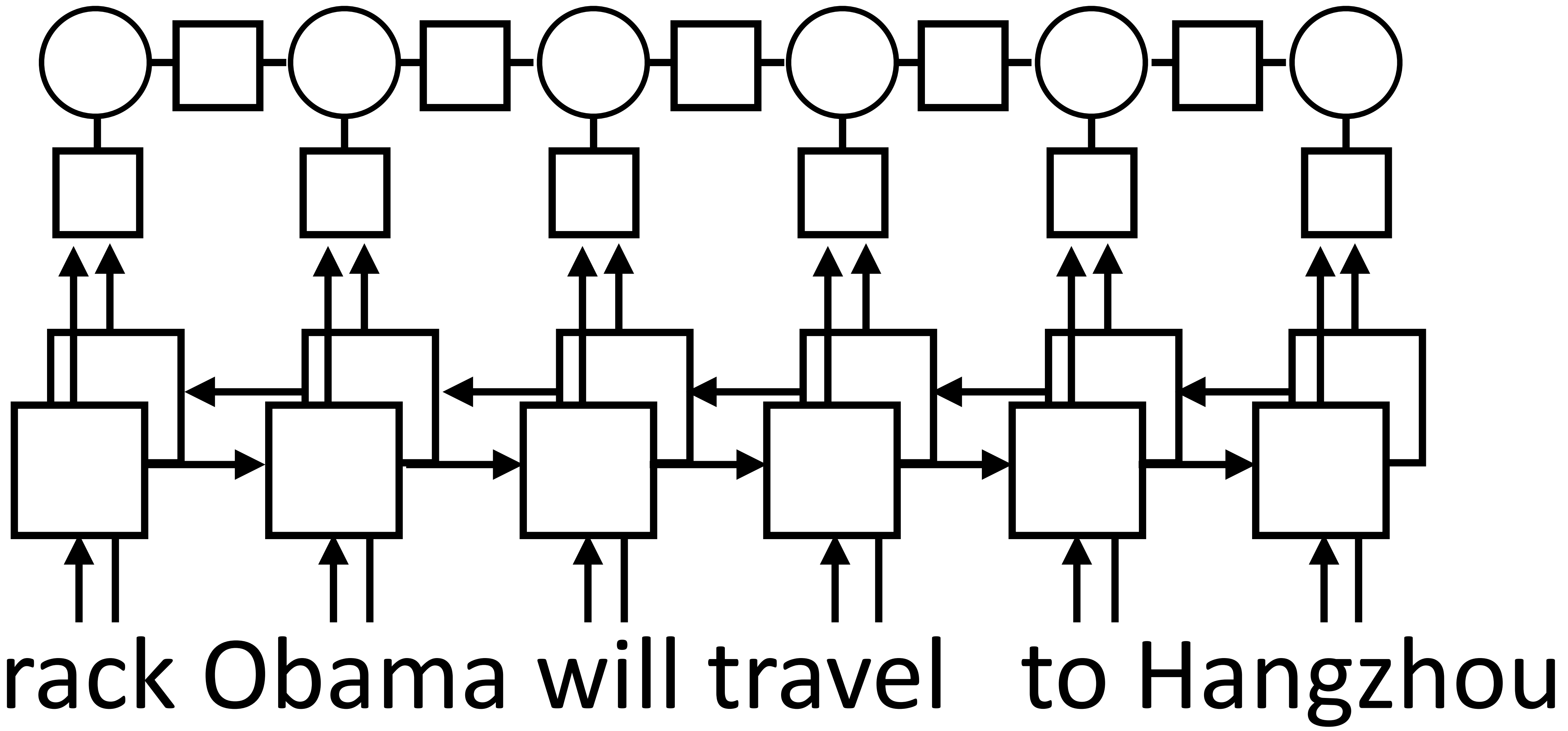

- Bidirectional LSTMs compute emission (or transition) potentials

LSTMs for NER

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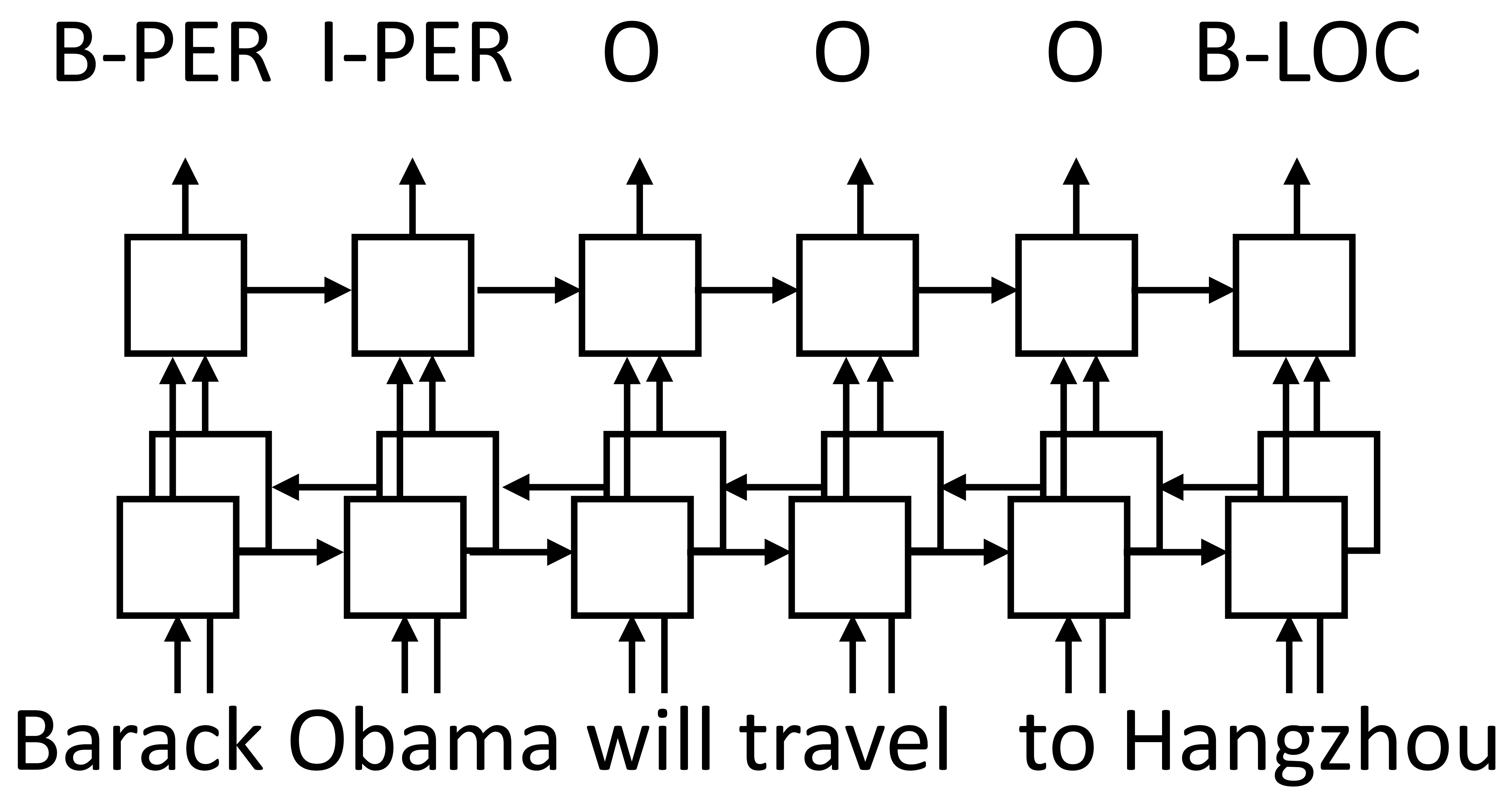
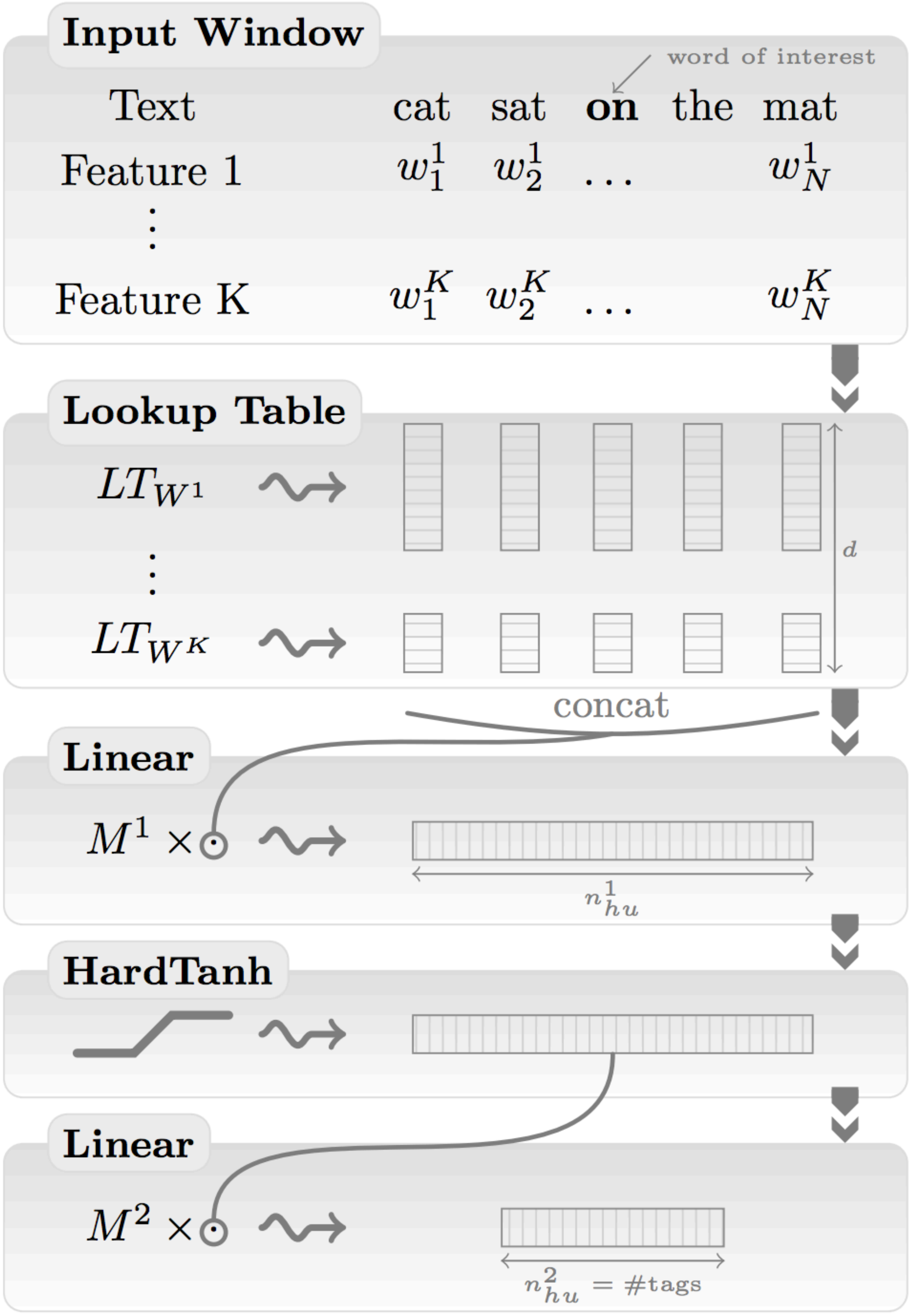


- How does this compare to neural CRF?

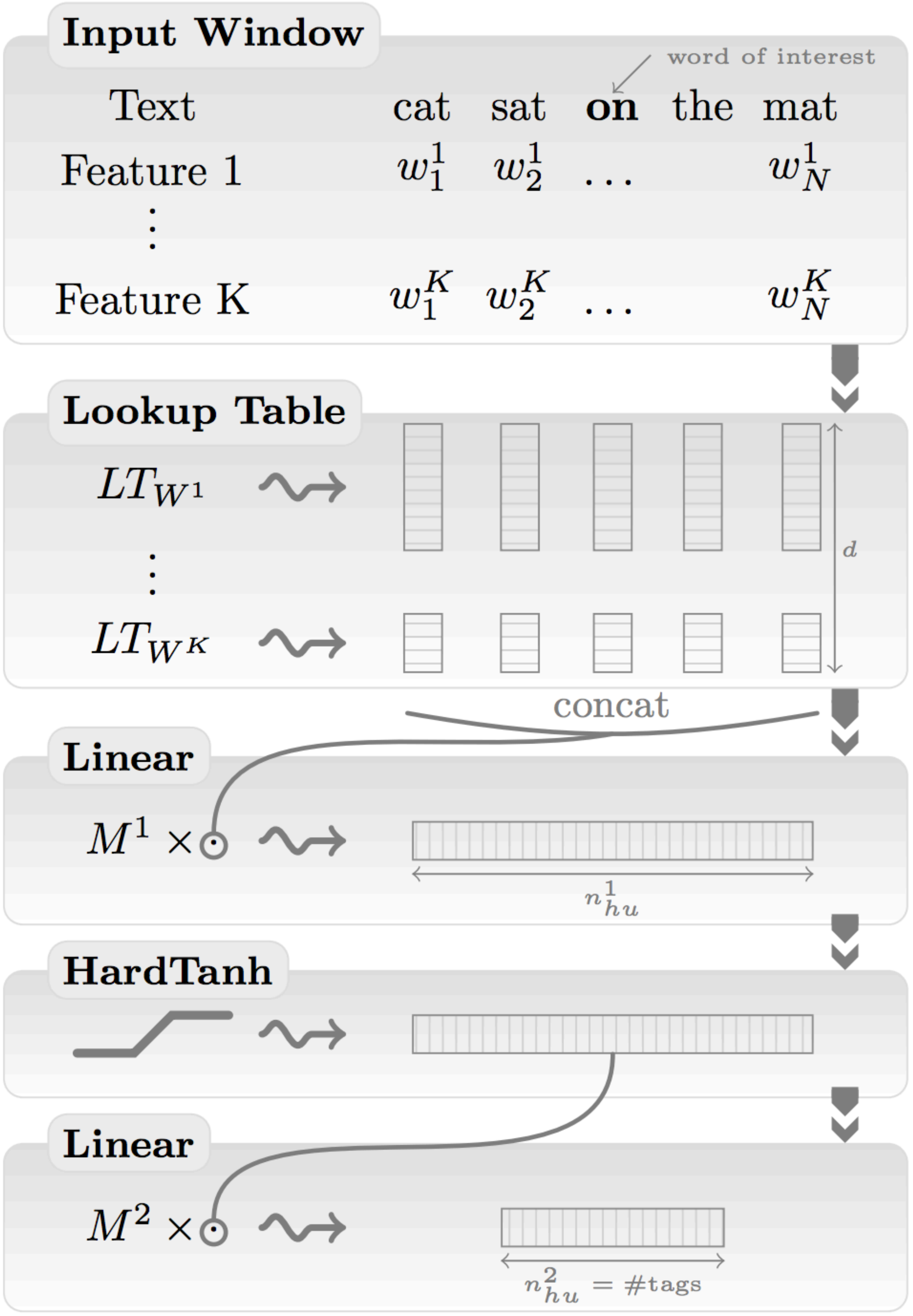
"NLP (Almost) From Scratch"



Collobert, Weston, et al. 2008, 2011

“NLP (Almost) From Scratch”

Approach	POS (PWA)	CHUNK (F1)	NER (F1)	SRL (F1)
Benchmark Systems	97.24	94.29	89.31	77.92
NN+WLL	96.31	89.13	79.53	55.40
NN+SLL	96.37	90.33	81.47	70.99
NN+WLL+LM1	97.05	91.91	85.68	58.18
NN+SLL+LM1	97.10	93.65	87.58	73.84
NN+WLL+LM2	97.14	92.04	86.96	58.34
NN+SLL+LM2	97.20	93.63	88.67	74.15



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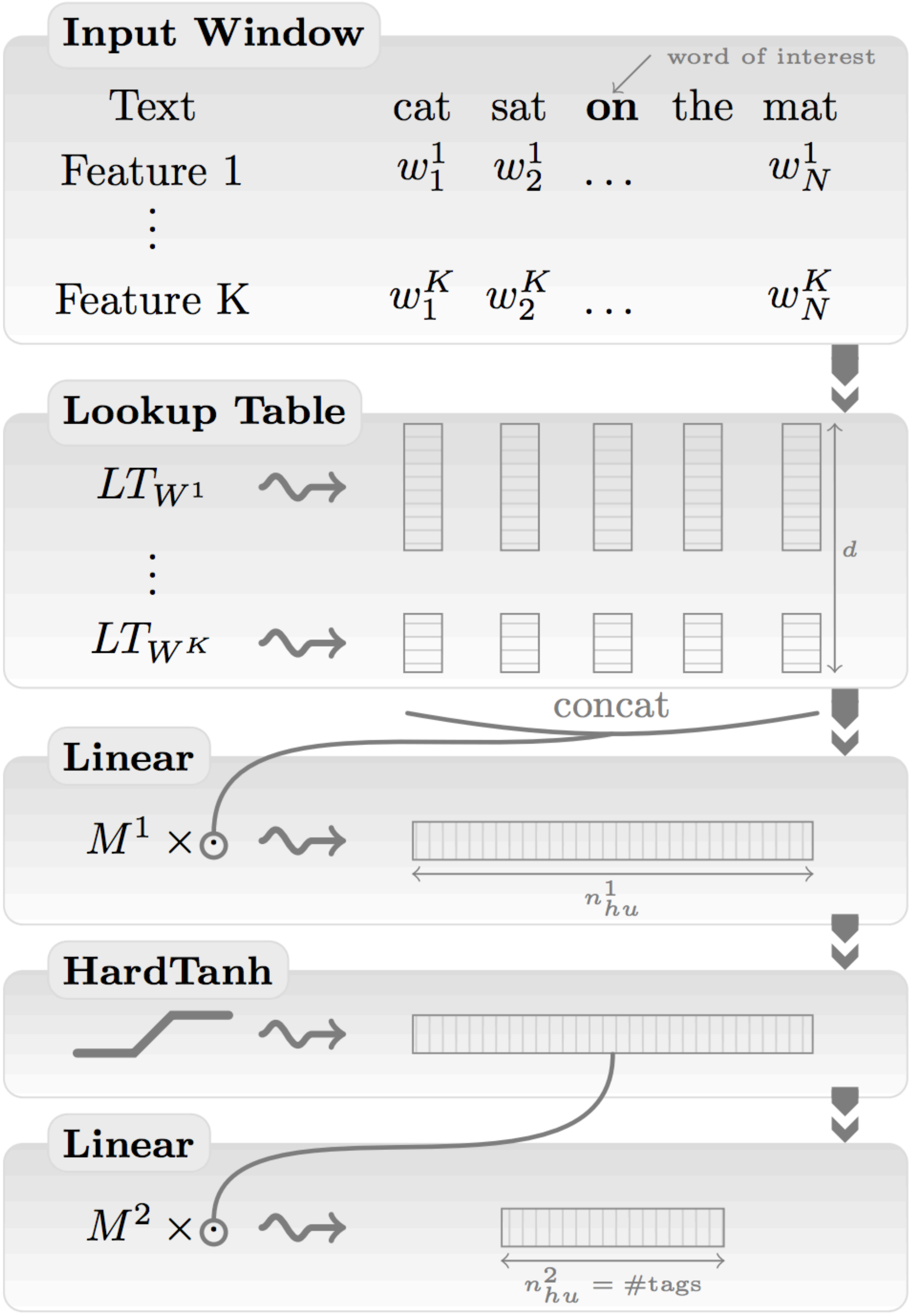

- WLL: independent classification; SLL: neural CRF

Collobert, Weston, et al. 2008, 2011

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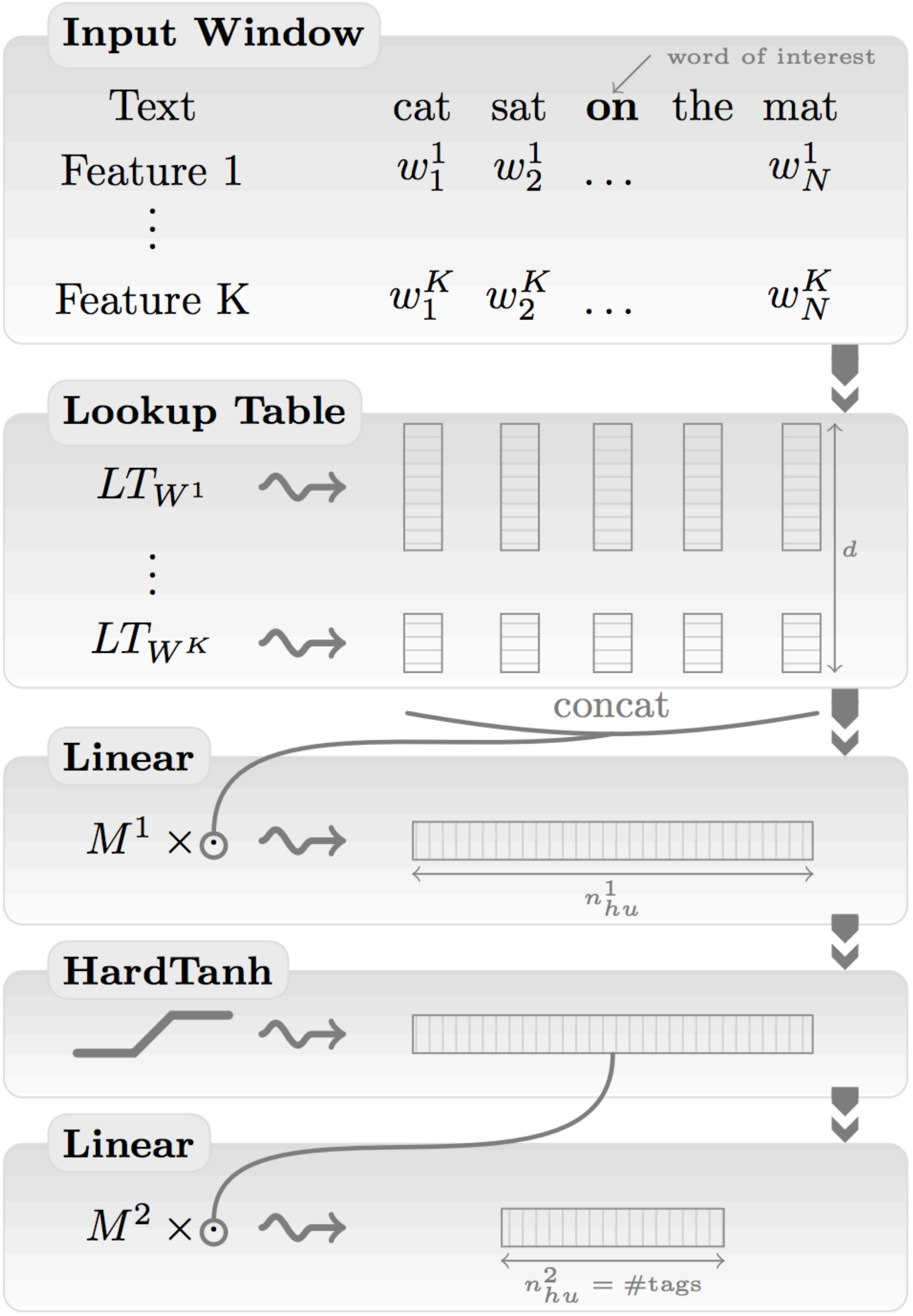

- WLL: independent classification; SLL: neural CRF
- LM2: word vectors learned from a precursor to word2vec/GloVe, trained for 2 weeks (!) on Wikipedia

Collobert, Weston, et al. 2008, 2011

CNN Neural CRFs

travel *to* ***Hangzhou*** *today* *for*

CNN Neural CRFs

- Append to each word vector an *embedding of the relative position* of that word

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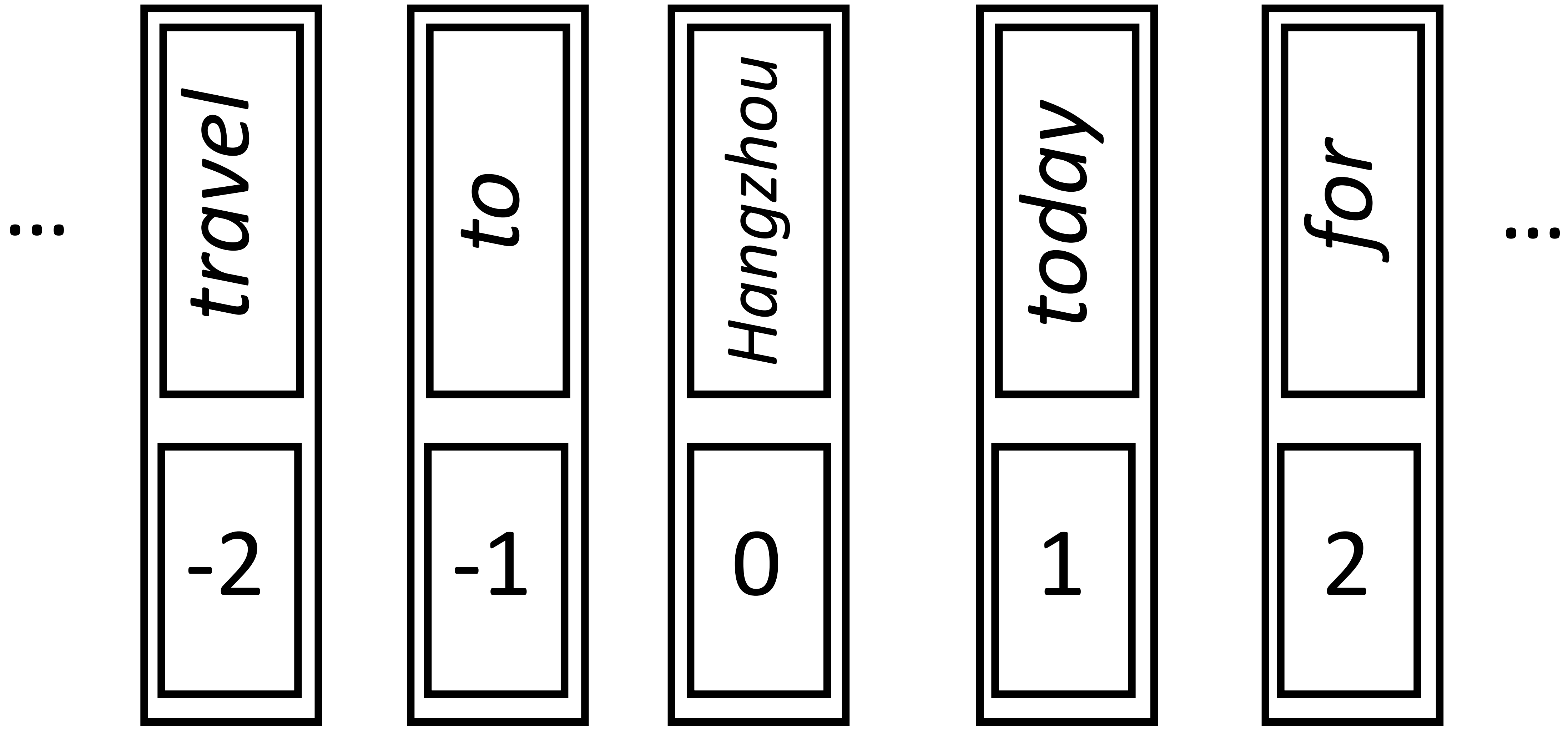

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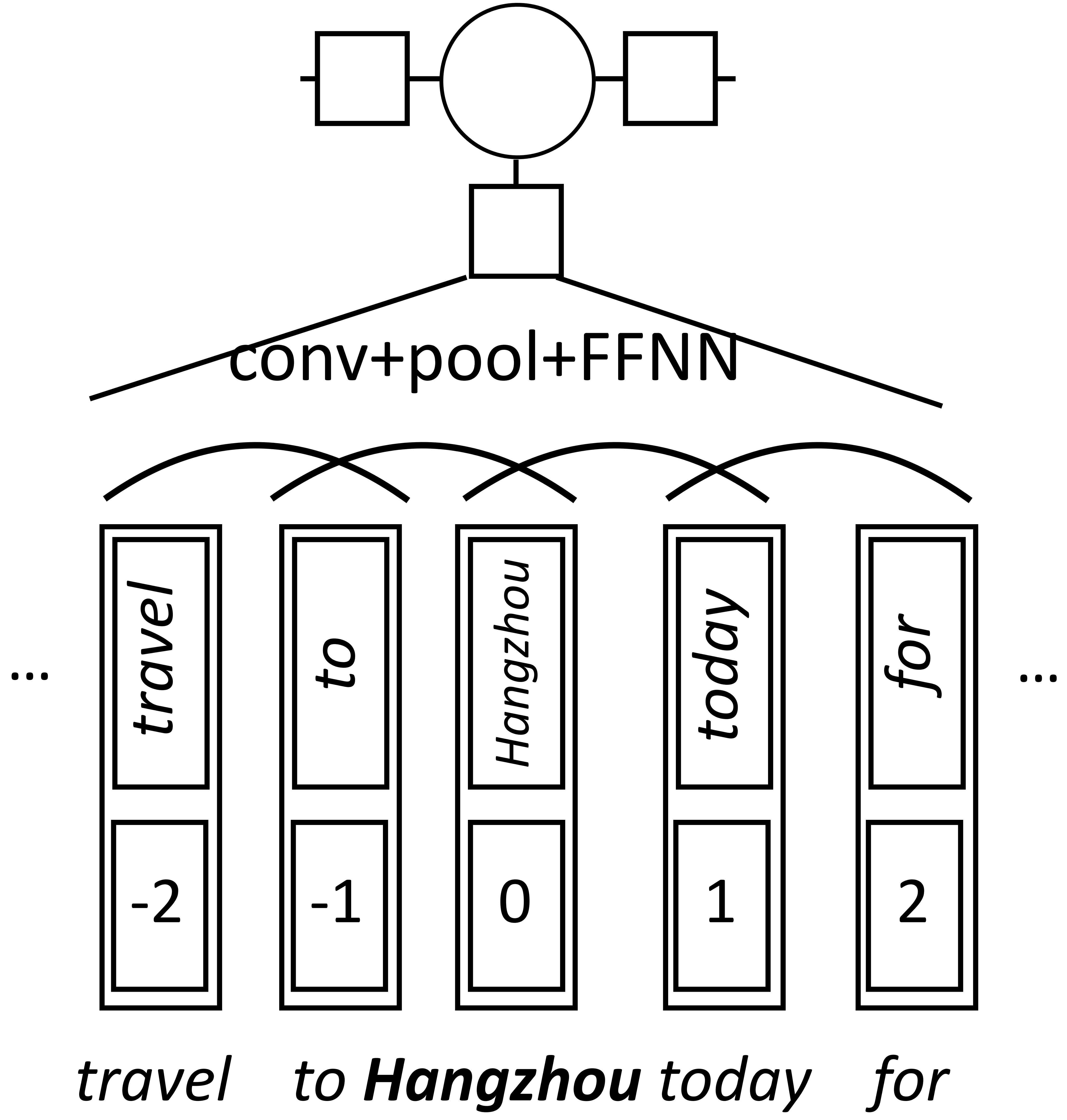

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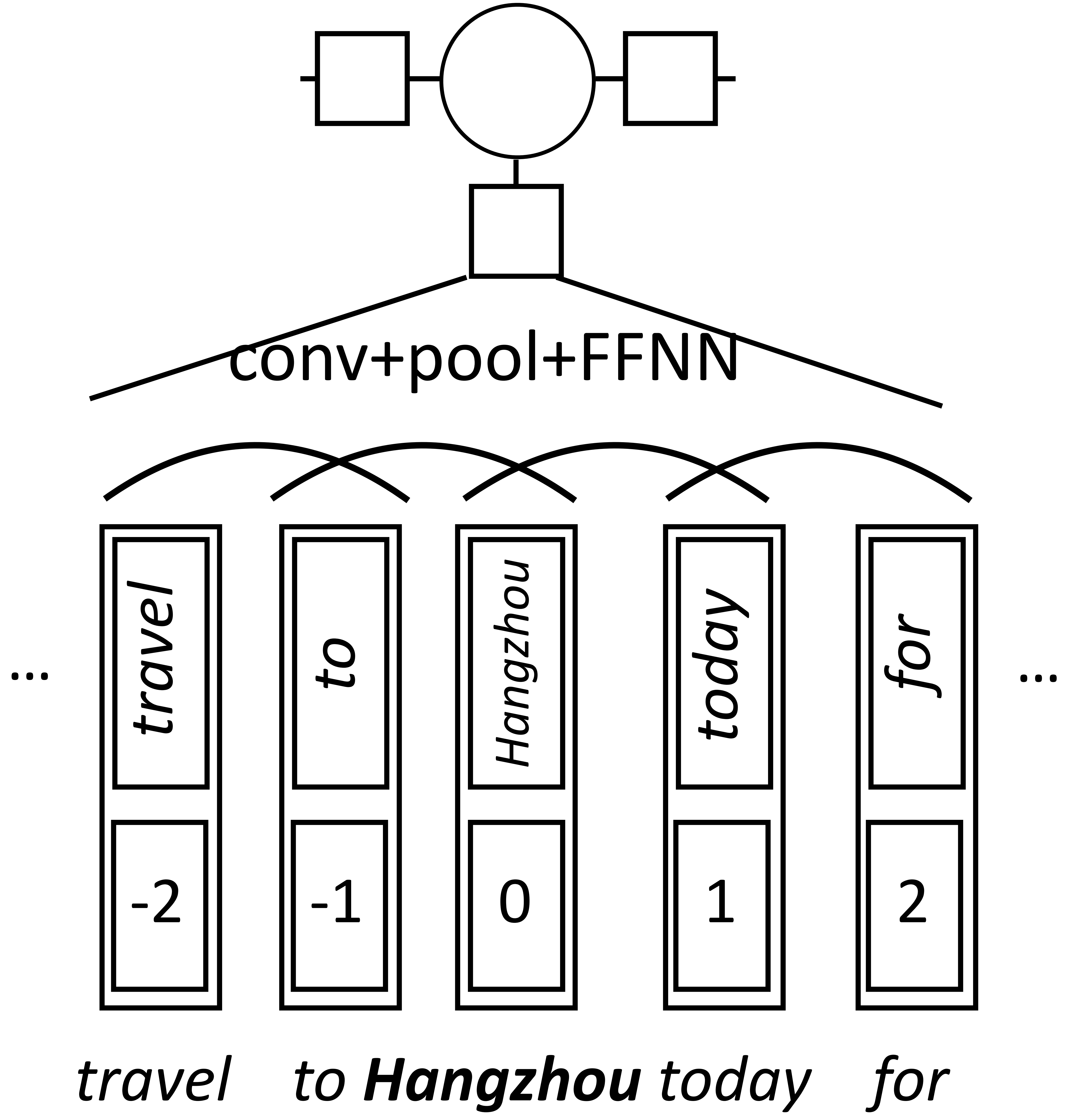

- Append to each word vector an *embedding of the relative position* of that word
- Convolution over the sentence produces a position-dependent representation

CNN NCRFs vs. FFNN NCRFs

Approach	**POS** (PWA)	**CHUNK** (F1)	**NER** (F1)	**SRL** (F1)
Benchmark Systems	97.24	94.29	89.31	77.92
	Window Approach			
NN+SLL+LM2	97.20	93.63	88.67	–
	Sentence Approach			
NN+SLL+LM2	97.12	93.37	88.78	74.15

- Sentence approach (CNNs) is comparable to window approach (FFNNs) except for SRL where they claim it works much better

Collobert and Weston 2008, 2011

Neural CRFs with LSTMs

- Neural CRF using character LSTMs to compute word representations

Chiu and Nichols (2015), Lample et al. (2016)

Neural CRFs with LSTMs

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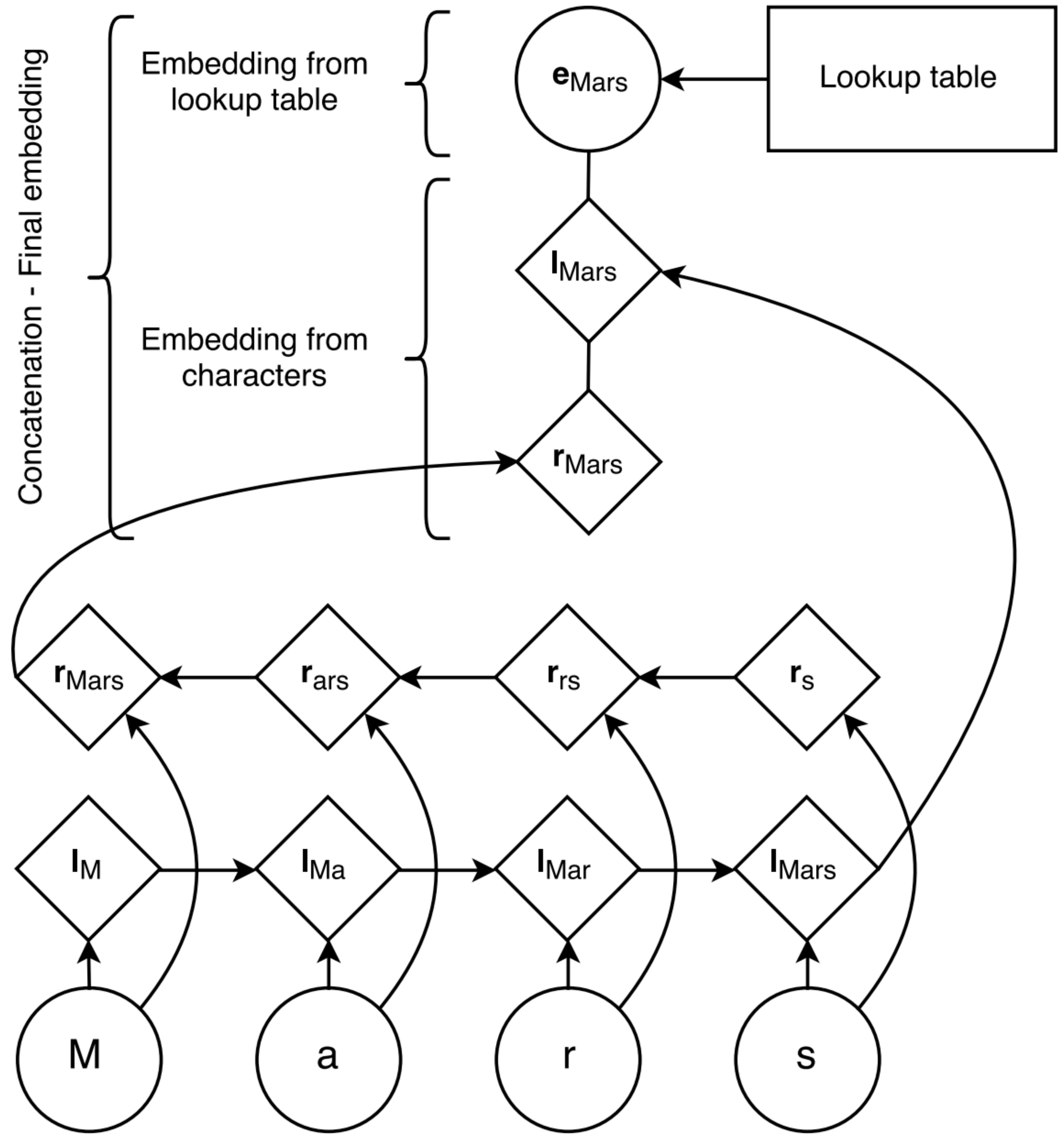

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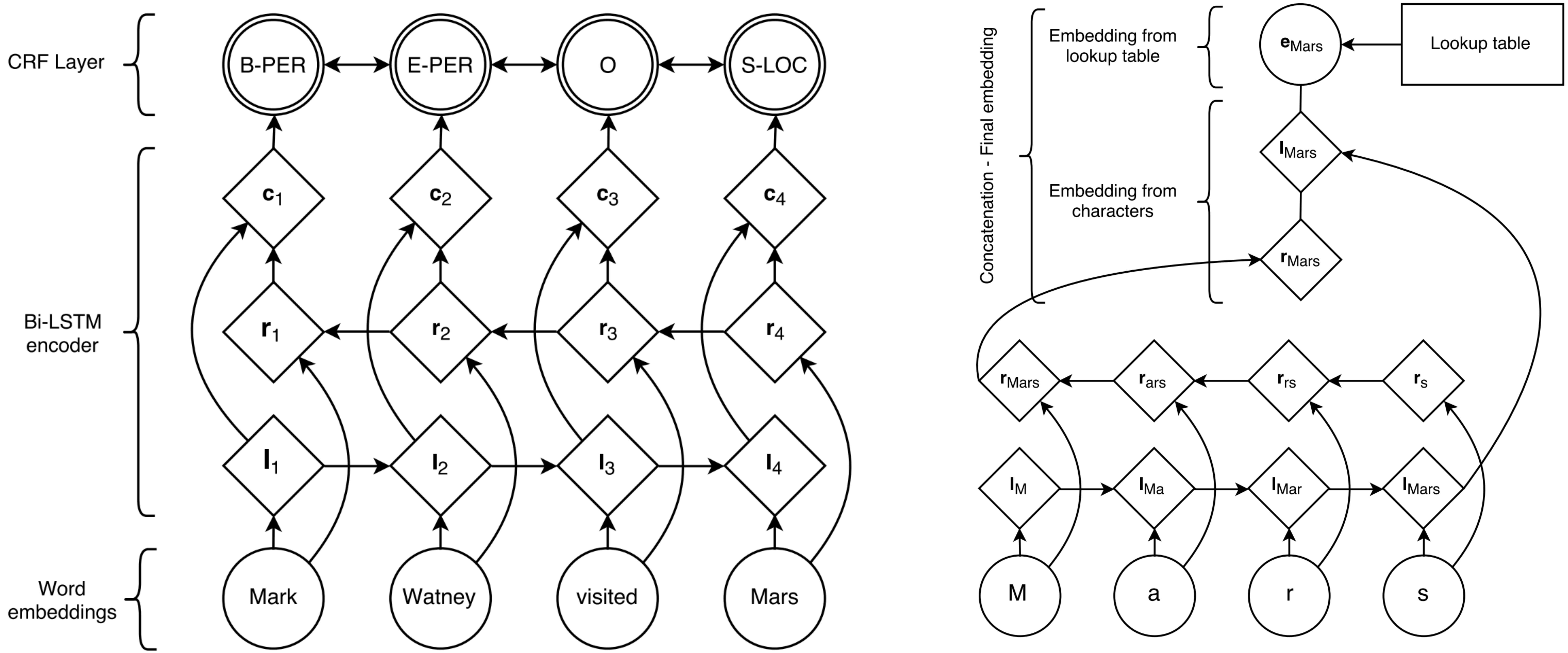

Chiu and Nichols (2015), Lample et al. (2016)

Neural CRFs with LSTMs

- Chiu+Nichols: character CNNs instead of LSTMs
- Lin/Passos/Luo: use external resources like Wikipedia
- LSTM-CRF captures the important aspects of NER: word context (LSTM), sub-word features (character LSTMs), outside knowledge (word embeddings)

Model	$\mathbf{F_1}$
Collobert et al. (2011)*	89.59
Lin and Wu (2009)	83.78
Lin and Wu (2009)*	90.90
Huang et al. (2015)*	90.10
Passos et al. (2014)	90.05
Passos et al. (2014)*	90.90
Luo et al. (2015)* + gaz	89.9
Luo et al. (2015)* + gaz + linking	**91.2**
Chiu and Nichols (2015)	90.69
Chiu and Nichols (2015)*	90.77
LSTM-CRF (no char)	90.20
LSTM-CRF	**90.94**

Chiu and Nichols (2015), Lample et al. (2016)

Takeaways

- CNNs are a flexible way of extracting features analogous to bag of n-grams, can also encode positional information

- All kinds of NNs can be integrated into CRFs for structured inference. Can be applied to NER, other tagging, parsing, …