

# Deep Learning for NLP: Recurrent Networks

COMP90042

Natural Language Processing

Lecture 8

Semester 1 2022 Week 4  
Jey Han Lau



THE UNIVERSITY OF  

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MELBOURNE

# Outline

- Recurrent Networks
- Long Short-term Memory Networks
- Applications

# N-gram Language Models

- Can be implemented using counts (with smoothing)
- Can be implemented using feed-forward neural networks
- Generates sentences like (trigram model):
  - *I saw a table is round and about*

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# N-gram Language Models

- Can be implemented using counts (with smoothing)
- Can be implemented using feed-forward neural networks
- Generates sentences like (trigram model):
  - *I saw a table is round and about*
- Problem: **limited context**

# Recurrent Neural Networks

# Recurrent Neural Network (RNN)

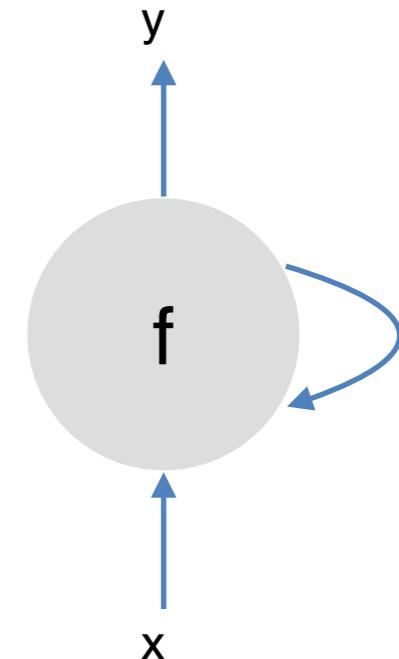
- Allow representation of arbitrarily sized inputs
- Core Idea: processes the input sequence one at a time, by applying a recurrence formula
- Uses a **state vector** to represent contexts that have been previously processed

# Recurrent Neural Network (RNN)

recurring function

$$s_i = f(s_{i-1}, x_i)$$

new state      previous state      input



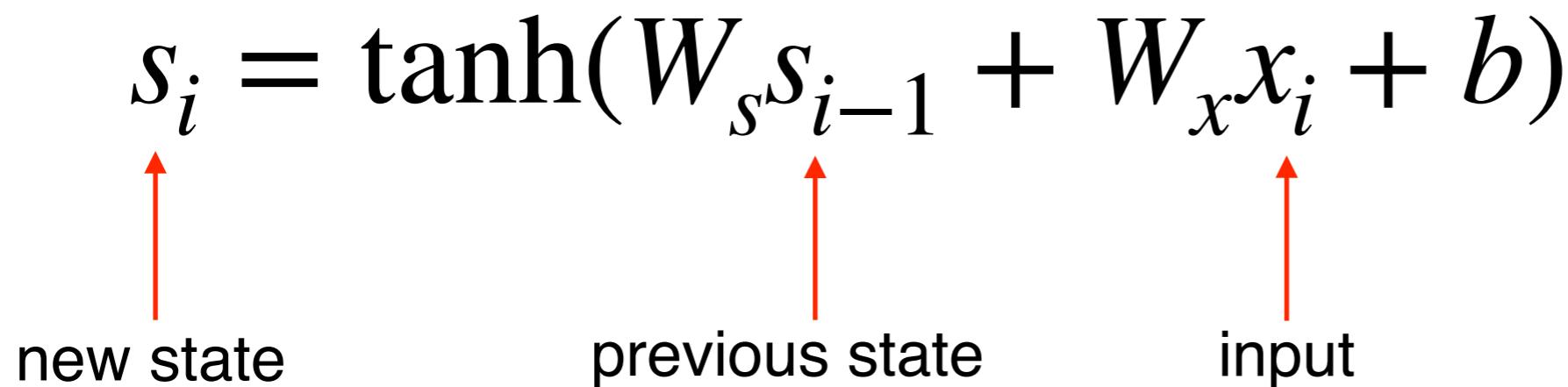
$$s_{i+1} = f(s_i, x_{i+1})$$

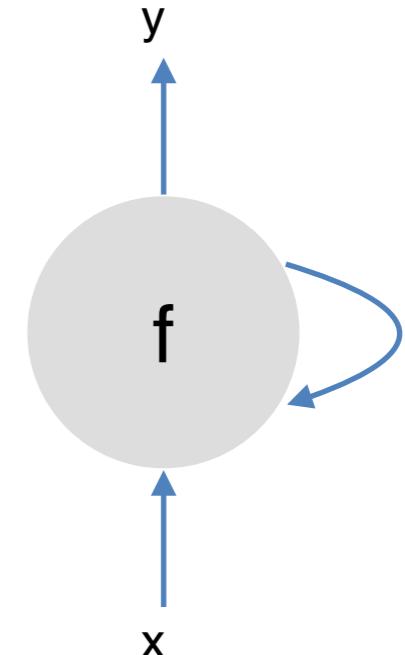
same recurring function

# Recurrent Neural Network (RNN)

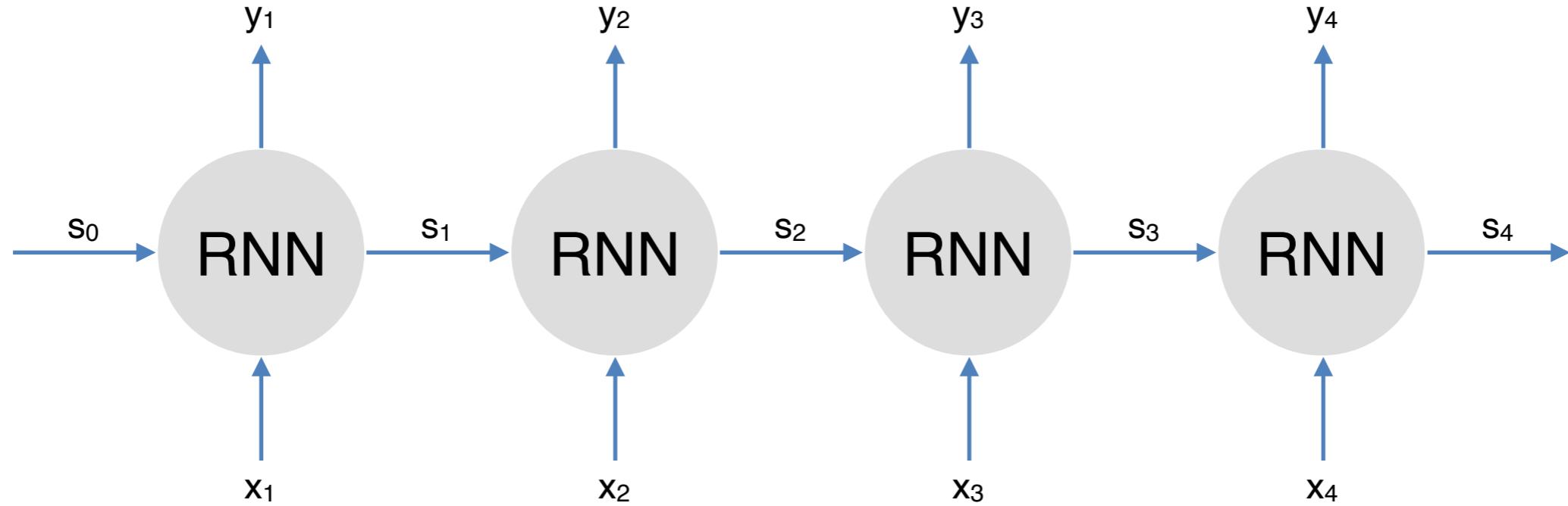
$$s_i = \tanh(W_s s_{i-1} + W_x x_i + b)$$

new state      previous state      input





# RNN Unrolled



$$s_i = \tanh(W_s s_{i-1} + W_x x_i + b)$$

← “Simple RNN”

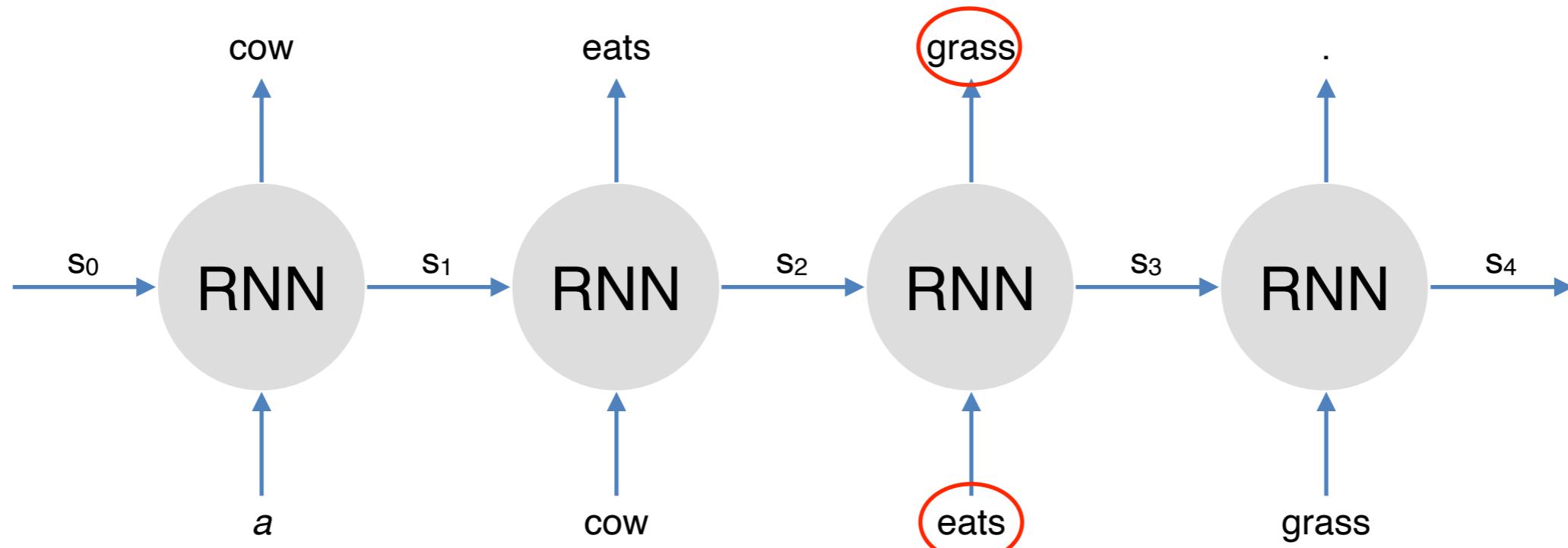
$$y_i = \sigma(W_y s_i)$$

- Same parameters ( $W_s$ ,  $W_x$ ,  $b$  and  $W_y$ ) are used across all time steps

# RNN Training

- An unrolled RNN is just a very deep neural network
  - But parameters are shared across all time steps
  - To train RNN, we just need to create the unrolled computation graph given an input sequence
  - And use backpropagation algorithm to compute gradients as usual
  - This procedure is called **backpropagation through time**
- $$\begin{aligned}s_4 &= R(s_3, x_4) \\ &= R(\overbrace{R(s_2, x_3)}^{s_3}, x_4) \\ &= R(R(\overbrace{R(s_1, x_2)}^{s_2}), x_3), x_4) \\ &= R(R(R(\overbrace{R(s_0, x_1)}^{s_1}), x_2), x_3), x_4)\end{aligned}$$

# (Simple) RNN for Language Model

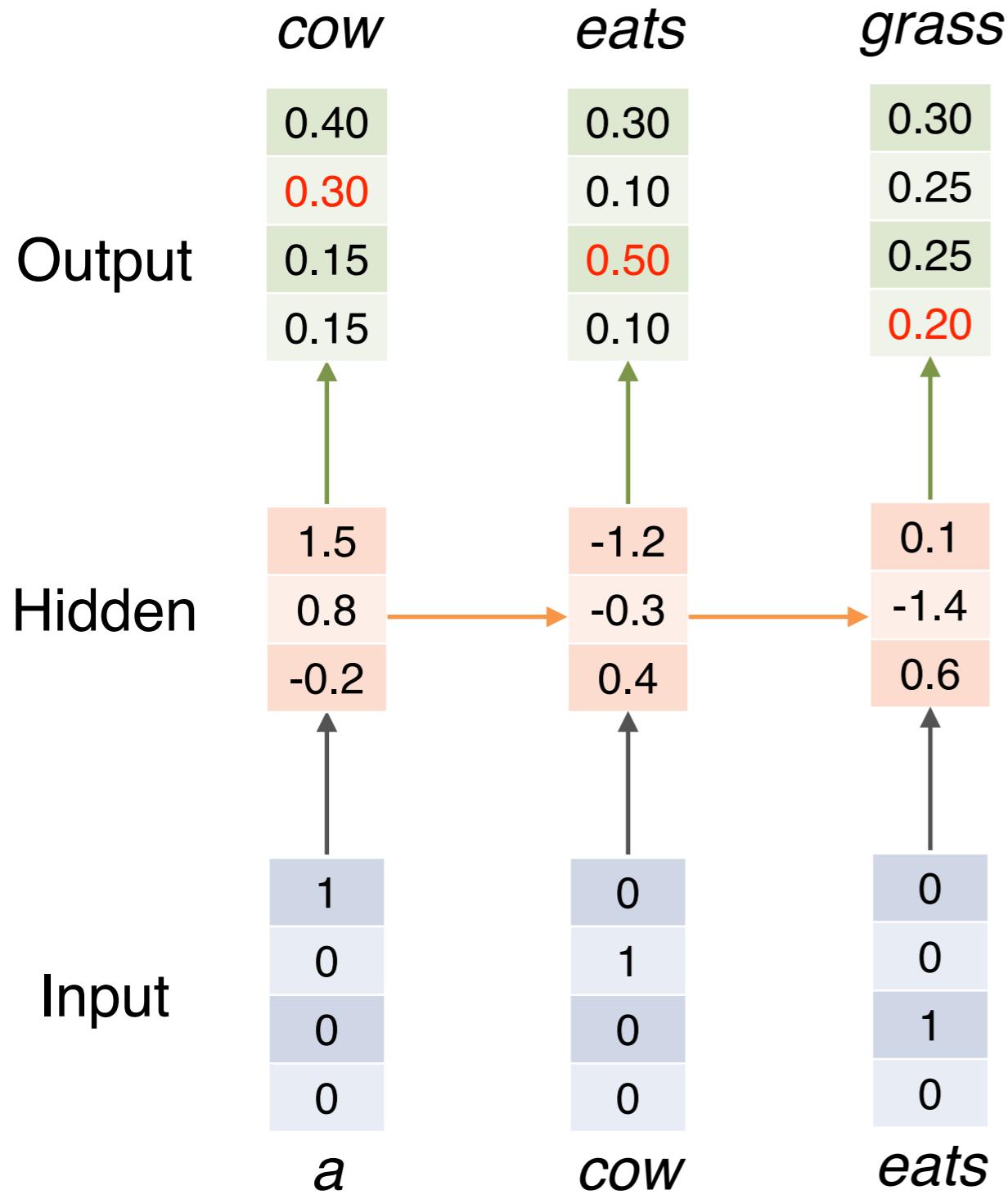


$$s_i = \tanh(W_s s_{i-1} + W_x x_i + b)$$

$$y_i = \text{softmax}(W_y s_i)$$

- $x_i$  is current word (e.g. "eats"); mapped to an embedding
- $s_{i-1}$  contains information of the previous words ("a", "cow")
- $y_i$  is the next word (e.g. "grass")

# RNN Language Model: Training



- Vocabulary: [ $a$ , *cow*, *eats*, *grass*]
- Training Example: *a cow eats grass*

$$s_i = \tanh(W_s s_{i-1} + W_x x_i + b)$$

$$y_i = \text{softmax}(W_y s_i)$$

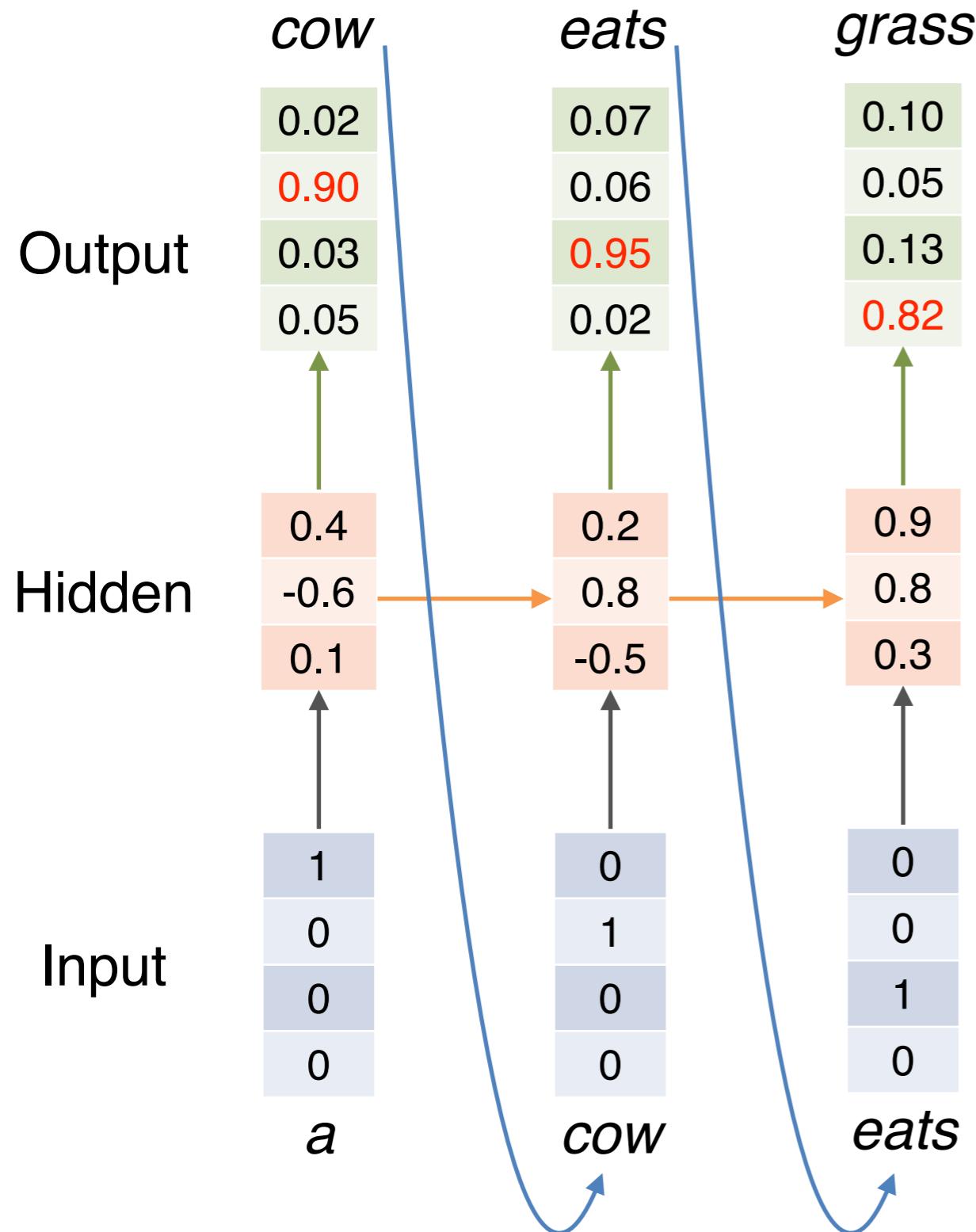
$$L_1 = -\log P(0.30)$$

$$L_2 = -\log P(0.50)$$

$$L_3 = -\log P(0.20)$$

$$L_{\text{total}} = L_1 + L_2 + L_3$$

# RNN Language Model: Generation



# What Are Some Potential Problems with This Generation Approach?

- Mismatch between training and decoding
- Error propagation: unable to recover from errors in intermediate steps
- Tends to generate “bland” or “generic” language

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# Long Short-term Memory Networks

# Language Model... Solved?

- RNN has the capability to model infinite context
- But can it actually capture long-range dependencies in practice?
- No... due to “**vanishing gradients**”
- Gradients in later steps diminish quickly during backpropagation
- Earlier inputs do not get much update

# Long Short-term Memory (LSTM)

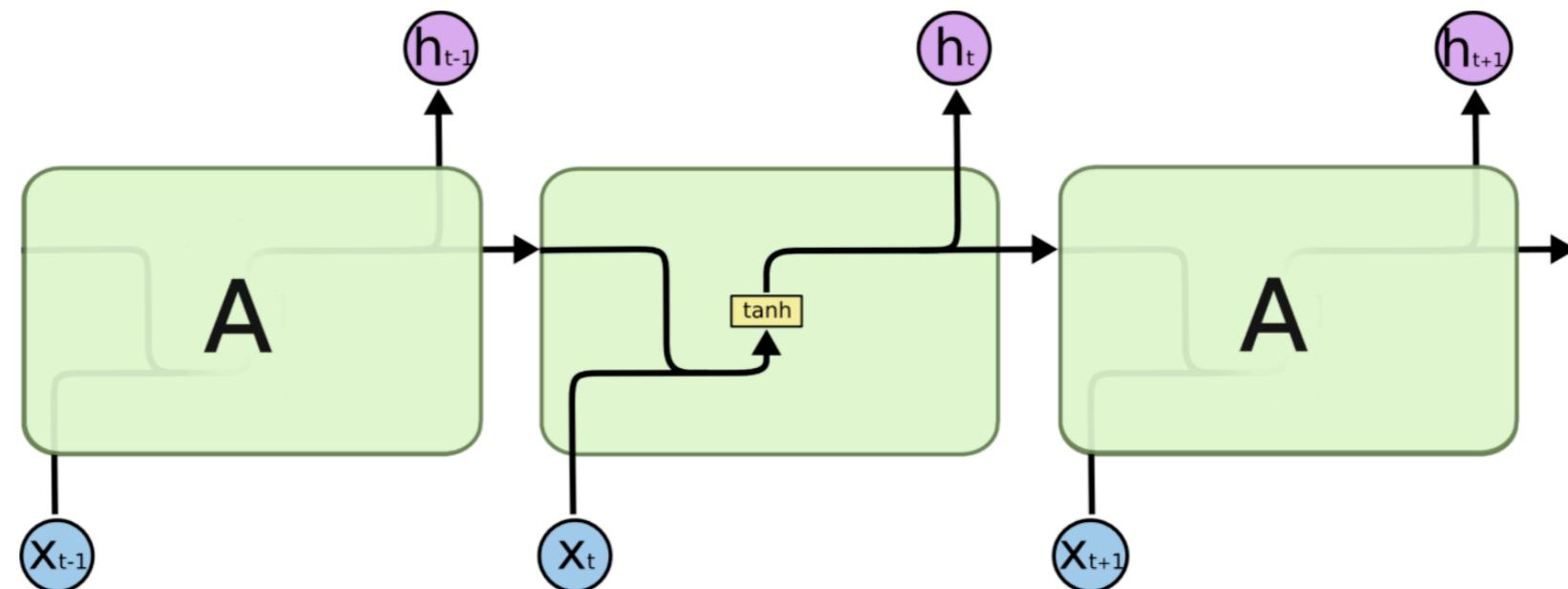
- LSTM is introduced to solve vanishing gradients
- Core idea: have “memory cells” that preserve gradients across time
- Access to the memory cells is controlled by “gates”
- For each input, a gate decides:
  - how much the new input should be written to the memory cell
  - and how much content of the current memory cell should be forgotten

# Gating Vector

- A gate  $\mathbf{g}$  is a vector
  - each element has values between 0 to 1
- $\mathbf{g}$  is multiplied component-wise with vector  $\mathbf{v}$ , to determine how much information to keep for  $\mathbf{v}$
- Use sigmoid function to produce  $\mathbf{g}$ :
  - values between 0 to 1

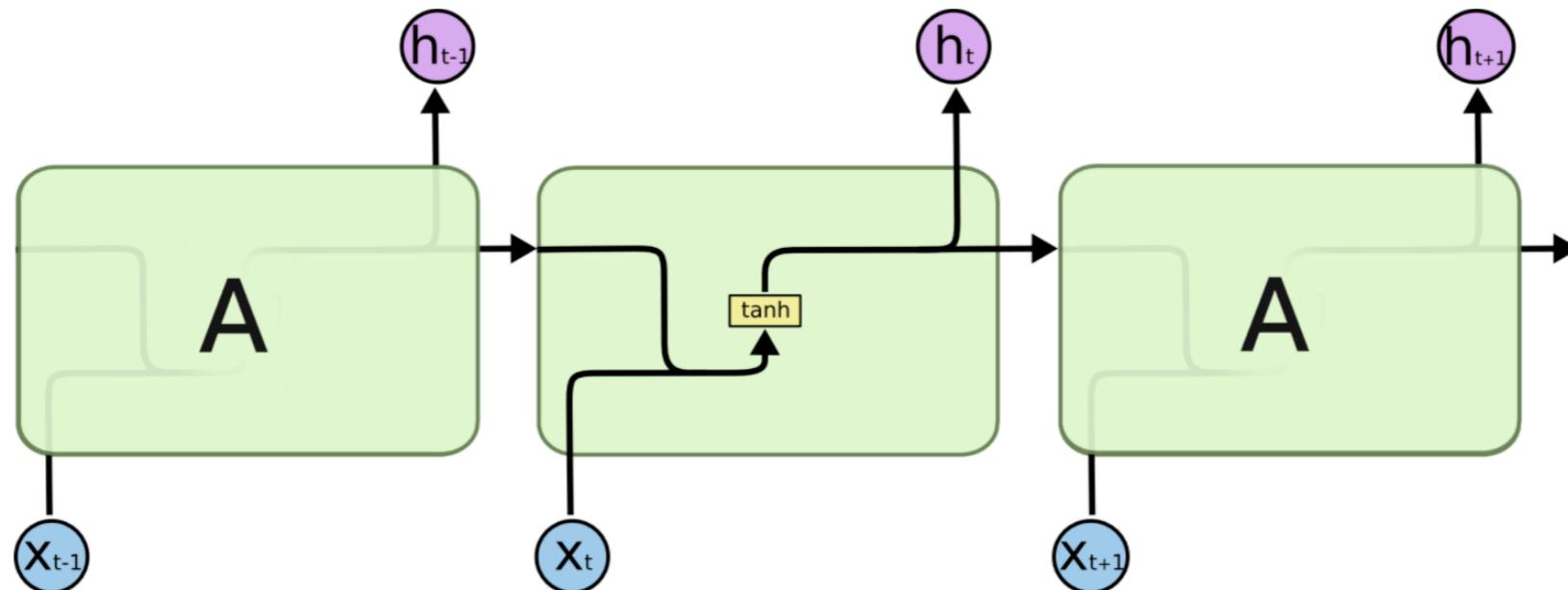
$$\begin{array}{ccc|c} \begin{matrix} 0.9 \\ 0.1 \\ 0.0 \end{matrix} & * & \begin{matrix} 2.5 \\ 5.3 \\ 1.2 \end{matrix} & = \\ \mathbf{g} & & \mathbf{v} & \begin{matrix} 2.3 \\ 0.5 \\ 0.0 \end{matrix} \end{array}$$

# Simple RNN vs. LSTM

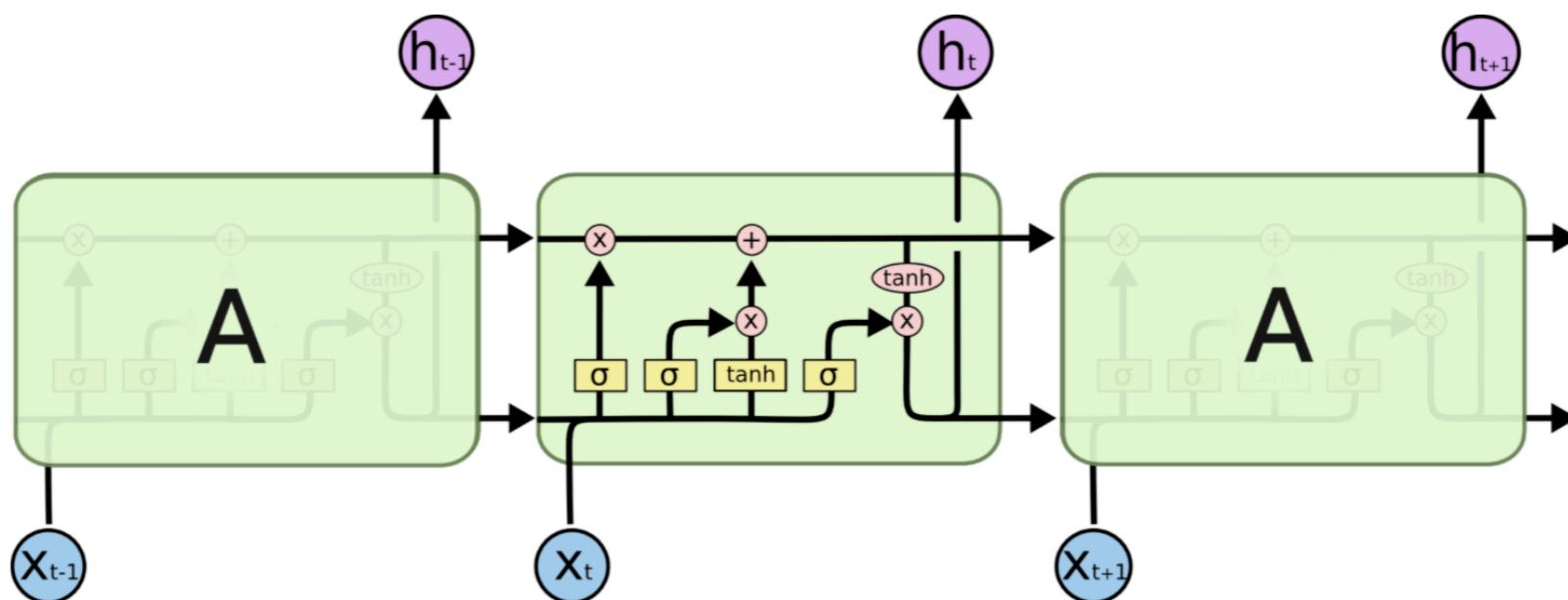


The repeating module in a standard RNN contains a single layer.

# Simple RNN vs. LSTM

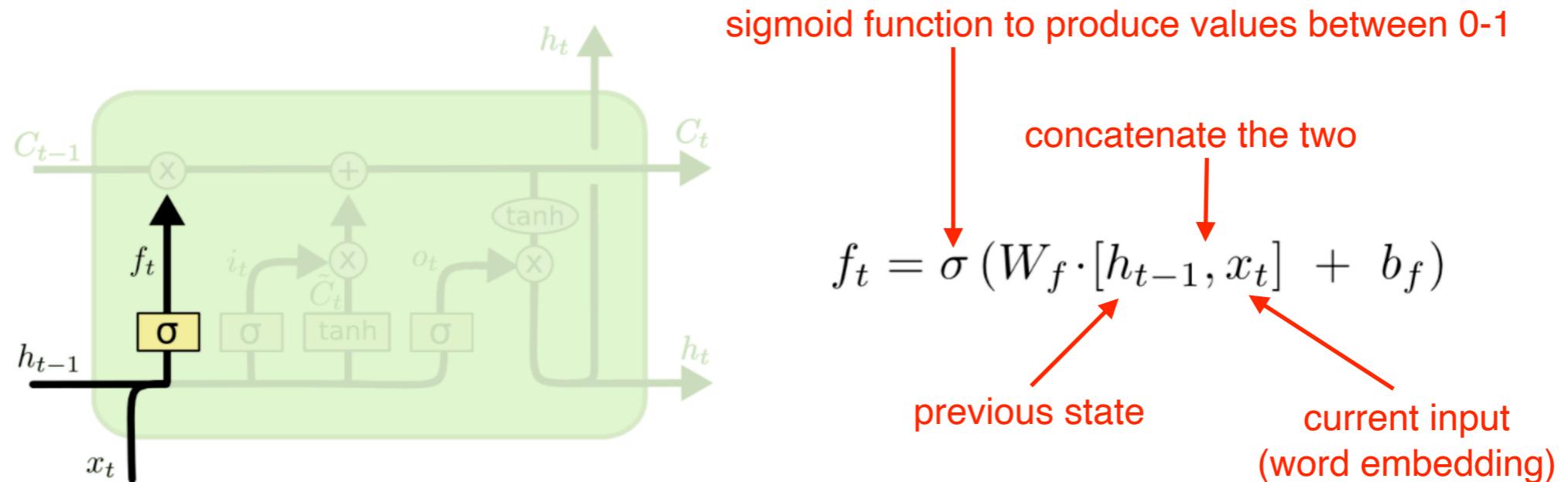


The repeating module in a standard RNN contains a single layer.



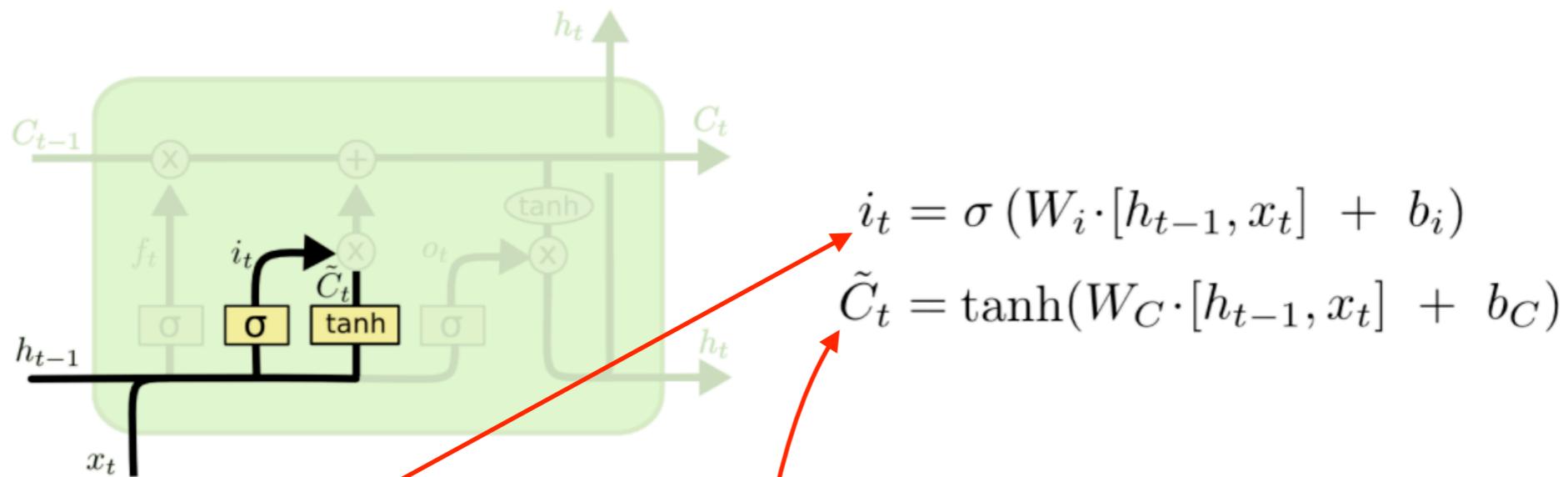
The repeating module in an LSTM contains four interacting layers.

# LSTM: Forget Gate



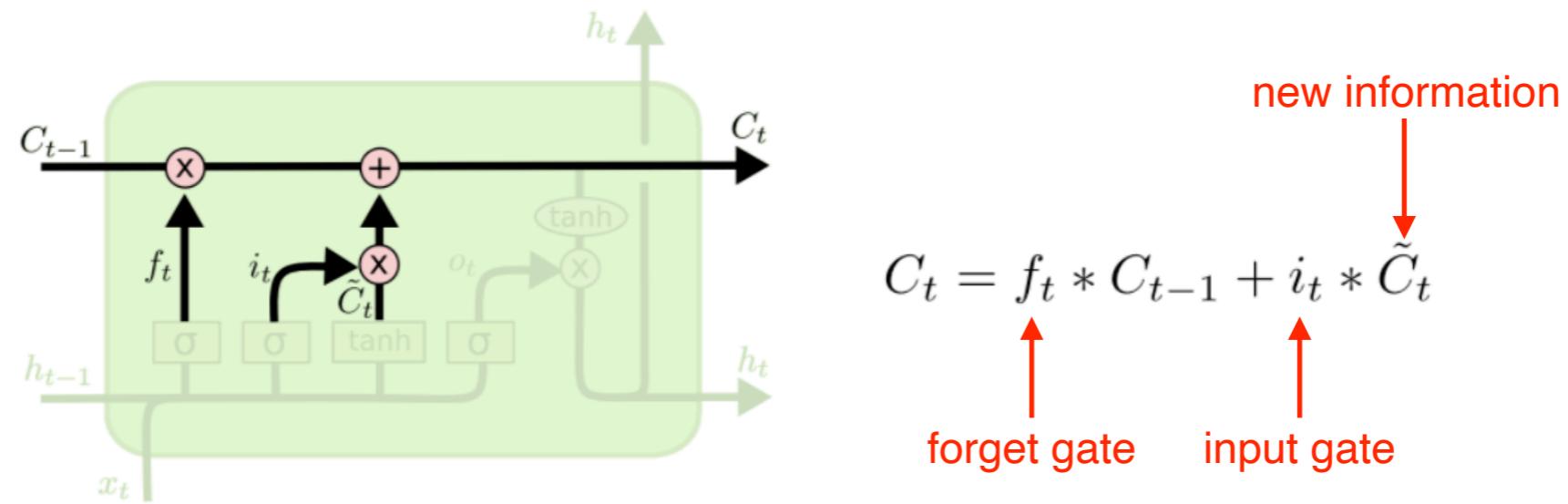
- Controls how much information to “forget” in the memory cell ( $C_{t-1}$ )
- *The cats that the boy likes*
- Memory cell was storing noun information (*cats*)
- The cell should now forget *cats* and store *boy* to correctly predict the singular verb *likes*

# LSTM: Input Gate



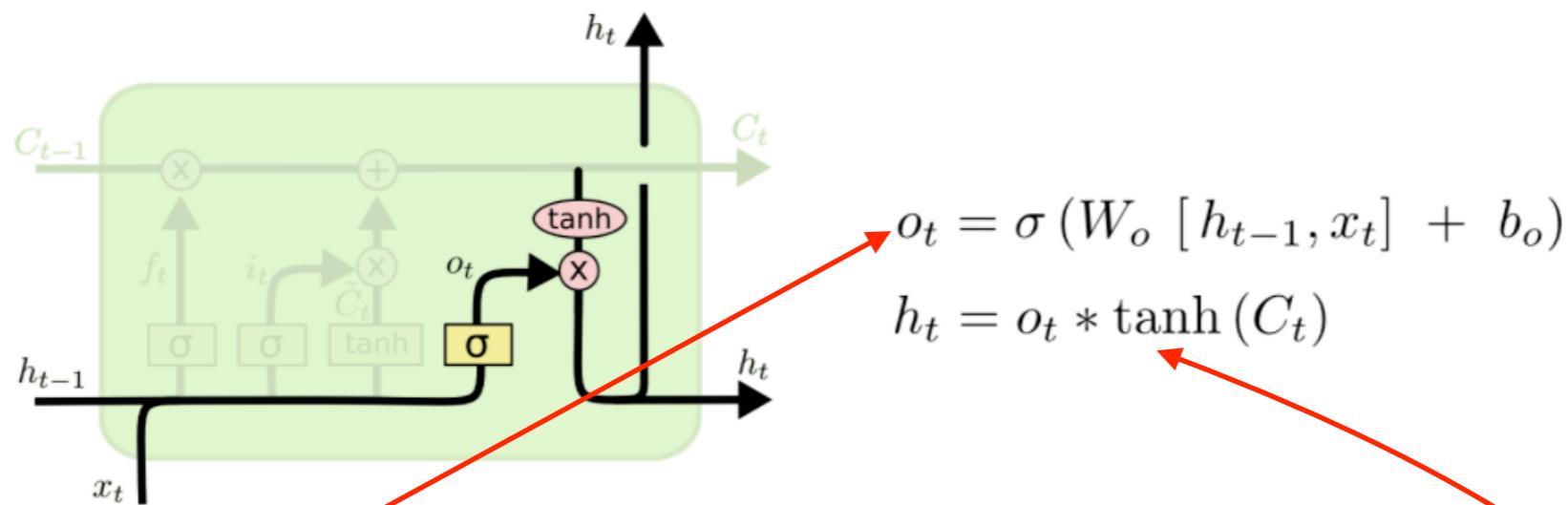
- Input gate controls how much new information to put to memory cell
- $\tilde{C}$ = new distilled information to be added
  - ▶ e.g. information about *boy*

# LSTM: Update Memory Cell



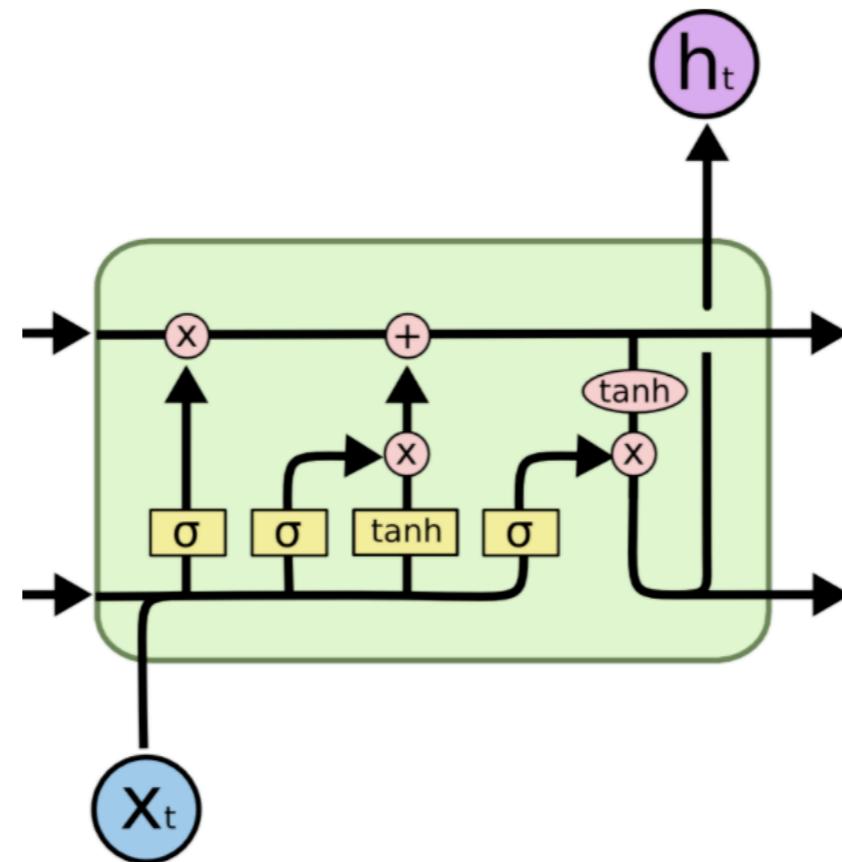
- Use the forget and input gates to update memory cell

# LSTM: Output Gate



- Output gate controls how much to distill the content of the memory cell to create the next state ( $h_t$ )

# LSTM: Summary



$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f)$$

$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i)$$

$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o)$$

$$\tilde{C}_t = \tanh(W_C \cdot [h_{t-1}, x_t] + b_C)$$

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

$$h_t = o_t * \tanh(C_t)$$

# What Are The Disadvantages of LSTM?

- Introduces a lot of new parameters
- Still unable to capture very long range dependencies
- Much slower than simple RNNs
- Produces inferior word embeddings

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# Applications

# Shakespeare Generator

PANDARUS:

Alas, I think he shall be come approached and the day  
When little strain would be attain'd into being never fed,  
And who is but a chain and subjects of his death,  
I should not sleep.

Second Senator:

They are away this miseries, produced upon my soul,  
Breaking and strongly should be buried, when I perish  
The earth and thoughts of many states.

DUKE VINCENTIO:

Well, your wit is in the care of side and that.

Second Lord:

They would be ruled after this chamber, and  
my fair nues begun out of the fact, to be conveyed,  
Whose noble souls I'll have the heart of the wars.

Clown:

Come, sir, I will make did behold your worship.

VIOLA:

I'll drink it.

- Training data = all works of Shakespeare
- Model: **character RNN**, hidden dimension = 512

# Wikipedia Generator

Naturalism and decision for the majority of Arab countries' capitalide was grounded by the Irish language by [[John Clair]], [[An Imperial Japanese Revolt]], associated with Guangzham's sovereignty. His generals were the powerful ruler of the Portugal in the [[Protestant Immineners]], which could be said to be directly in Cantonese Communication, which followed a ceremony and set inspired prison, training. The emperor travelled back to [[Antioch, Perth, October 25|21]] to note, the Kingdom of Costa Rica, unsuccessful fashioned the [[Thrales]], [[Cynth's Dajoard]], known in western [[Scotland]], near Italy to the conquest of India with the conflict. Copyright was the succession of independence in the slop of Syrian influence that was a famous German movement based on a more popular servicious, non-doctrinal and sexual power post. Many governments recognize the military housing of the [[Civil Liberalization and Infantry Resolution 265 National Party in Hungary]], that is sympathetic to be to the [[Punjab Resolution]] (PJS) [<http://www.humah.yahoo.com/guardian.cfm/7754800786d17551963s89.htm>]. Official economics Adjoint for the Nazism, Montgomery was swear to advance to the resources for those Socialism's rule, was starting to signing a major tripad of aid exile.]

- Training data = 100MB of Wikipedia raw data

# Code Generator

```
/*
 * Increment the size file of the new incorrect UI_FILTER group information
 * of the size generatively.
 */
static int indicate_policy(void)
{
    int error;
    if (fd == MARN_EPT) {
        /*
         * The kernel blank will coeld it to userspace.
         */
        if (ss->segment < mem_total)
            unblock_graph_and_set_blocked();
        else
            ret = 1;
        goto bail;
    }
    segaddr = in_SB(in.addr);
    selector = seg / 16;
    setup_works = true;
    for (i = 0; i < blocks; i++) {
        seq = buf[i++];
        bpf = bd->bd.next + i * search;
        if (fd) {
            current = blocked;
        }
    }
    rw->name = "Getjbbregs";
    bprm_self_clearl(&iv->version);
    regs->new = blocks[(BPF_STATS << info->historidac)] | PFMR_CLOBATHINC_SECONDS << 12;
    return segtable;
}
```

# Deep-Speare

- Generates Shakespearean sonnets

```
python sonnet_gen.py -m trained_model/ -d 1
```

Temperature = 0.6 – 0.8

```
01 [0.43] with joyous gambols gay and still array  
02 [0.44] no longer when he twas, while in his day  
03 [0.00] at first to pass in all delightful ways  
04 [0.40] around him, charming and of all his days
```

```
python sonnet_gen.py -m trained_model/ -d 2
```

Temperature = 0.6 – 0.8

```
01 [0.44] shall i behold him in his cloudy state  
02 [0.00] for just but tempteth me to stop and pray  
03 [0.00] a cry: if it will drag me, find no way  
04 [0.40] from pardon to him, who will stand and wait
```

## Computers produce poetry by the metre

Mark Bridge, Technology Correspondent

Tuesday July 31 2018, 12.01am BST, The Times



Shakespeare's 12th sonnet, illustrated by John Gilbert  
CULTURE CLUB/GETTY IMAGES

Sonnets written by a computer are superior to Shakespeare's in some respects — and the general public is unable to tell the difference between the two, researchers say.

Computer scientists have trained a "neural network" using 2,600 sonnets taken from a free online database and put the system to work

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### Emerging Tech

# Move over, Shakespeare: This sonnet-writing A.I. is the poet we need

By Luke Dormehl  
July 30, 2018



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## Can YOU spot the real Shakespearean sonnet? The AI learning how write its own poetry

- Researchers at IBM used 2600 sonnets to train their AI
- Researchers asked workers from a crowdsourcing website to rate them
- Found they were unable to distinguish them from the real deal
- However, experts were more critical and said they still lacked real emotion

By [MARK PRIGG FOR DAILYMAIL.COM](#)

PUBLISHED: 05:25 AEDT, 28 July 2018 | UPDATED: 05:56 AEDT, 28 July 2018



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50 shares



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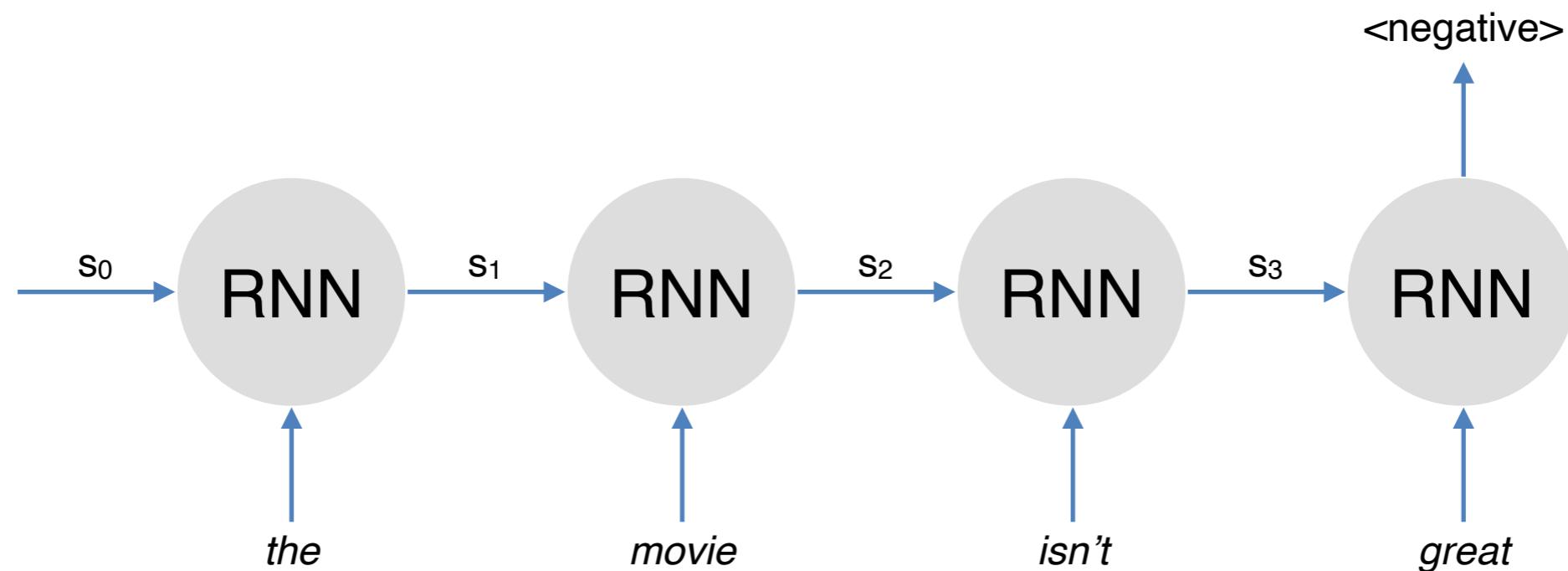
Researchers have revealed an AI that they hope will one day write a perfect Shakespearean sonnet.

Researchers at IBM used created a sonnet writing AI.

They trained it using 2600 sonnets taken from a free online database of out-of-copyright books called Project Gutenberg.

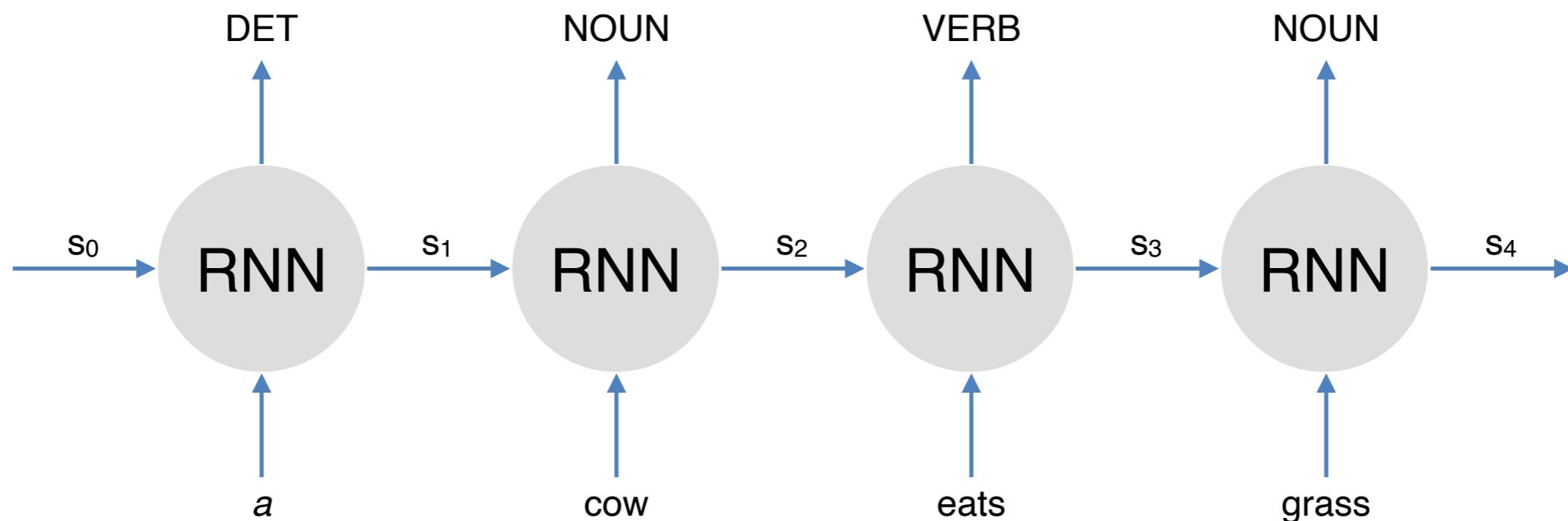
# Text Classification

- RNNs can be used in a variety of NLP tasks
- Particularly suited for tasks where order of words matter, e.g. sentiment classification



# Sequence Labeling

- Also good for sequence labelling problems, e.g. POS tagging



# Variants

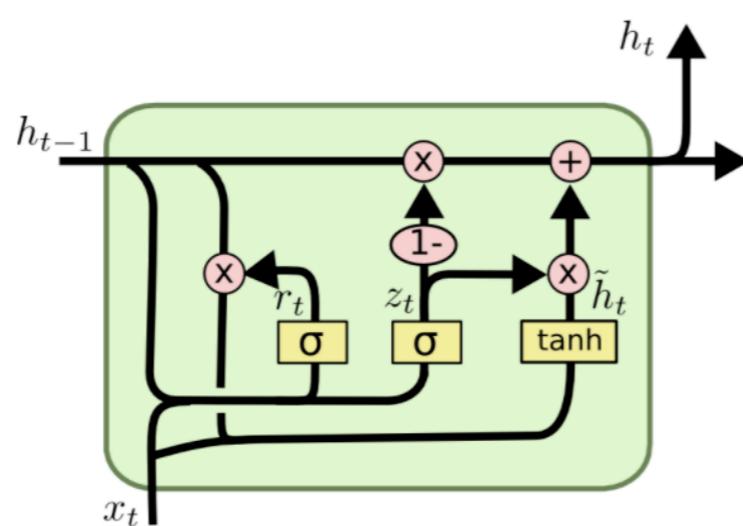
- Peephole connections

- ▶ Allow gates to look at cell state

$$f_t = \sigma \left( W_f [C_{t-1}, h_{t-1}, x_t] + b_f \right)$$

- Gated recurrent unit (GRU)

- ▶ Simplified variant with only 2 gates and no memory cell



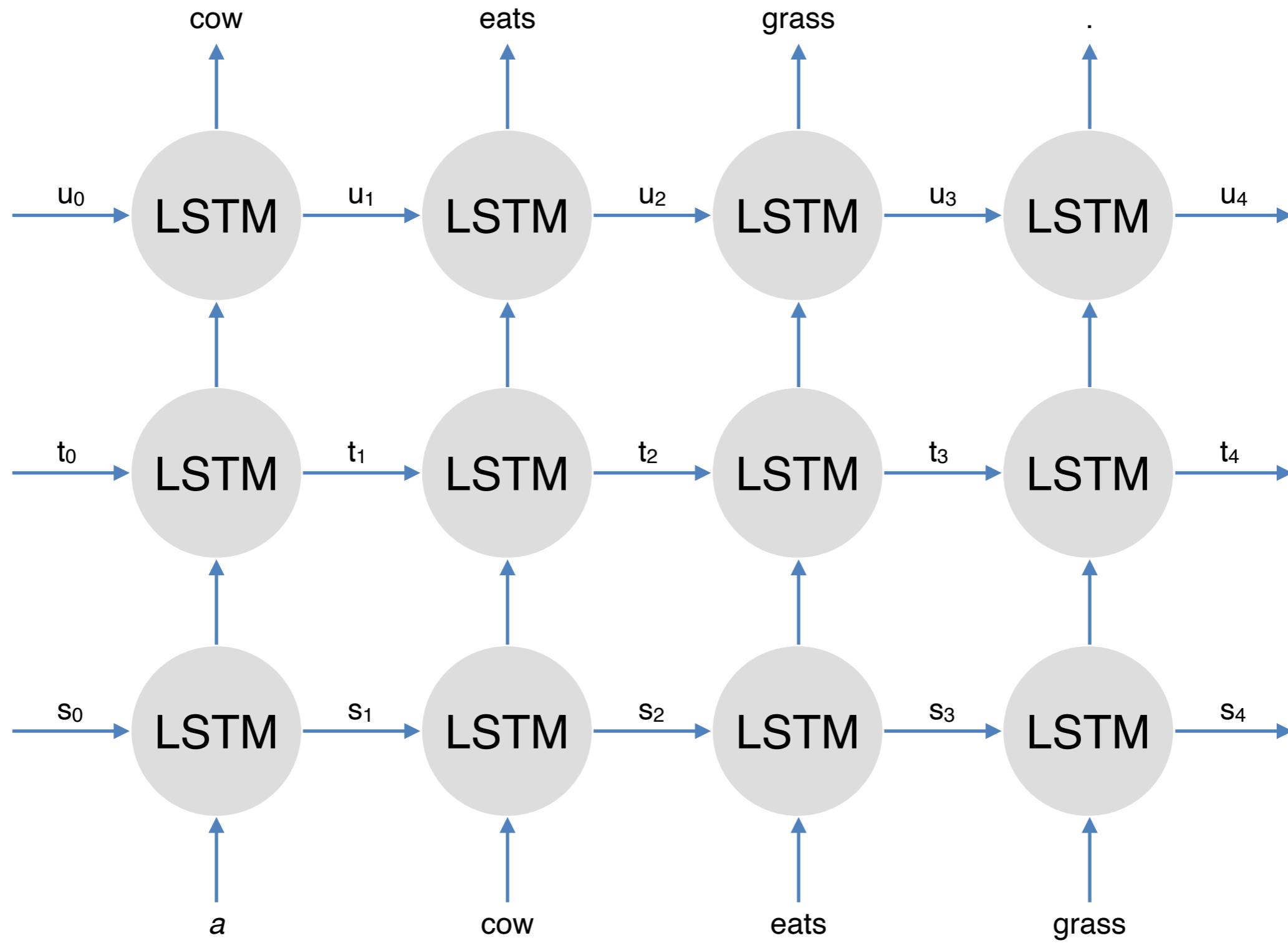
$$z_t = \sigma (W_z \cdot [h_{t-1}, x_t])$$

$$r_t = \sigma (W_r \cdot [h_{t-1}, x_t])$$

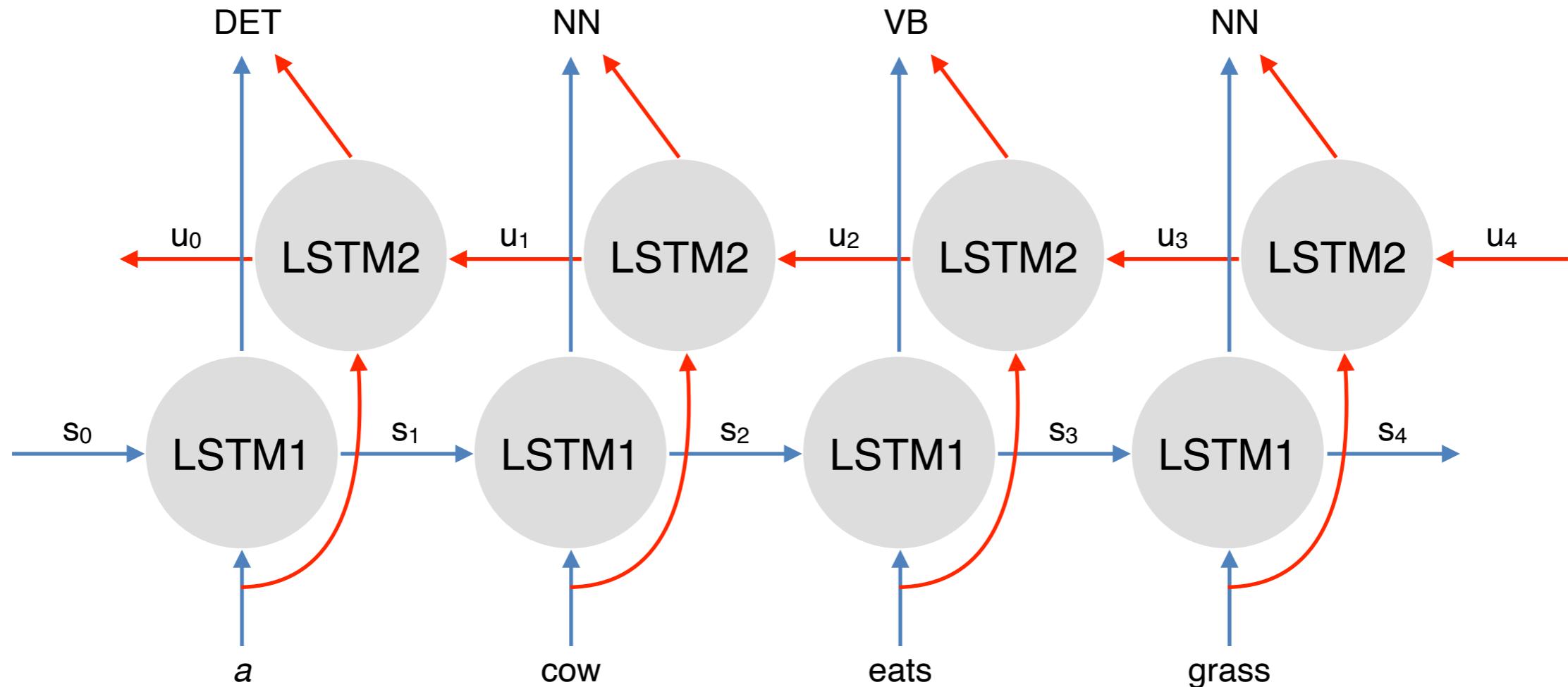
$$\tilde{h}_t = \tanh (W \cdot [r_t * h_{t-1}, x_t])$$

$$h_t = (1 - z_t) * h_{t-1} + z_t * \tilde{h}_t$$

# Multi-layer LSTM



# Bidirectional LSTM



$$y_i = \text{softmax}(W_s[s_i, u_i])$$

use information from both  
forward and backward LSTM

# Final Words

- Pros
  - Has the ability to capture long range contexts
  - Just like feedforward networks: flexible
- Cons
  - Slower than FF networks due to sequential processing
  - In practice doesn't capture long range dependency very well (evident when generating very long text)
  - In practice also doesn't stack well (multi-layer LSTM)
  - Less popular nowadays due to the emergence of more advanced architectures (Transformer; lecture 11!)

# A Machine-Generated Poem on RNN

Neural networks that never end,  
learning from data again and again.  
Modeling the world in all its detail,  
a recurrent neural network.

# Readings

- G15, Section 10 & 11
- JM3 Ch. 9.2-9.6