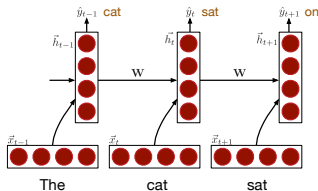# Sequence Models

Jordan Boyd-Graber

University of Maryland

RNNs

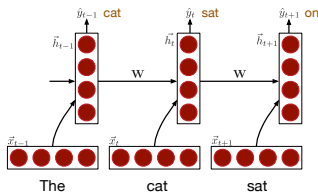Slides adapted from Richard Socher

Neural Language Models

- Mostly used for predicting the next word (more on this later)

- Or using learned representation (*a la* Word2Vec)

Neural Language Models

- Mostly used for predicting the next word (more on this later)

- Or using learned representation (*a la* Word2Vec)
- But today, sentiment analysis

Sentiment Analysis

Positive Sentiment

Rachel Romero ✓
@missrachel

There's nothing a great burrito can't solve.

Tweet übersetzen

Negative Sentiment

Iwaspoisoned.com ✓
@iwaspoisoned_

Chipotle Mexican Grill - Plano, Texas - Dined on 9/21/22 3:39pm. 4x Barbacoa burrito bowls, after eating stomach was unsettled. Got home and within 1-2h... Food Poisoning iwaspoisoned.com/i/NRO2VD3 #chipotlemexicangrill #mexican #burritobowl #barbacoa #meat

Dictionaries for Sentiment Analysis
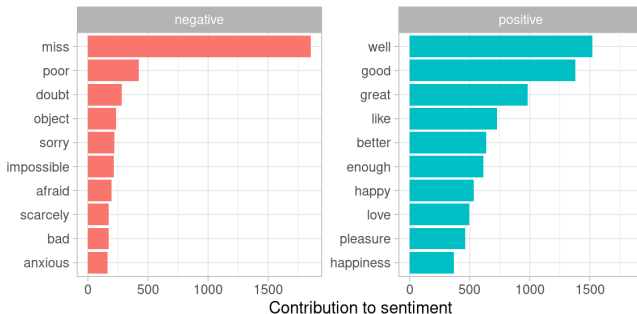
(Image from Julia Silge and David Robinson)

- Connection to simple pre-neural approach
- Shows how the RNN can use its hidden vector to encode state

What goes into a Recurrent Neural Network?

- What are tokens? Words or characters?
- What are your representations?

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$$e[\text{"cromulent"}] = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{1}$$

$$e[\text{"meh"}] = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{2}$$

$$e[\text{"chazwazzer"}] = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{3}$$

Recurrent Neural Networks
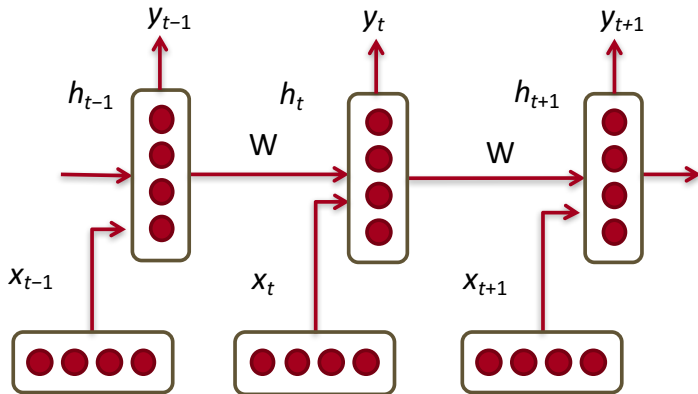
- Condition on all previous words
- Hidden state at each time step

Hidden State by Fiat

- $h_{t,1}$ is the total number of positive sentiment words seen by time t
- $h_{t,2}$ is the total number of negative sentiment words seen by time t
- y_t is the number of positive sentiment words minus negative sentiment words

RNN parameters (abstract)

$$h_t = f(\mathbf{W}^{(hh)} \vec{h}_{t-1} + \mathbf{W}^{(hx)} \vec{x}_t + \vec{b}^{(h)}) \tag{4}$$

$$\hat{y}_t = W^{(S)} h_t \tag{5}$$

$$\tag{6}$$

- Learn parameter h_0 to initialize hidden layer
- x_t is representation of input (e.g., word embedding)
- $\hat{y}$ is the output (in our example, sentiment)

Basic RNN parameters (concrete)

Dimension of x and h are both 2 (positive and negative)

$$\mathbf{W}^{(hh)} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{7}$$

$$\mathbf{W}^{(hx)} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{8}$$

$$\vec{b}^{(h)} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{9}$$

Example

Input Token	Input	Hidden	Output
This			
movie			
is			
an			
exquisite			
masterpiece			
despite			
the			
questionable			
title			

Example

Input Token	Input	Hidden	Output
This	$x_1^\mathsf{T} = [00]$		
movie	$x_2^\mathsf{T} = [00]$		
is	$x_3^\mathsf{T} = [00]$		
an	$x_4^\mathsf{T} = [00]$		
exquisite	$x_5^\mathsf{T} = [10]$		
masterpiece	$x_6^\mathsf{T} = [10]$		
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Input Token	Input	Hidden	Output
This	$x_1^\mathsf{T} = [00]$	$h_1^\mathsf{T} = [00]$	$y_1 = 0$
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an	$x_4^\mathsf{T} = [00]$	$h_4^\mathsf{T} = [00]$	$y_4 = 0$
exquisite	$x_5^\mathsf{T} = [10]$	$h_5^\mathsf{T} = [10]$	$y_5 = 1$
masterpiece	$x_6^\mathsf{T} = [10]$	$h_6^\mathsf{T} = [20]$	$y_6 = 2$
despite	$x_7^\mathsf{T} = [00]$	$h_7^\mathsf{T} = [20]$	$y_7 = 2$
the	$x_8^\mathsf{T} = [00]$	$h_8^\mathsf{T} = [20]$	$y_8 = 2$
questionable	$x_9^\mathsf{T} = [01]$	$h_9^\mathsf{T} = [21]$	$y_9 = 1$
title	$x_{10}^\mathsf{T} = [00]$	$h_{10}^\mathsf{T} = [21]$	$y_{10} = 1$

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This doesn't actually use the sequence!

So let's look at inverting sentiment!

RNN parameters 2.0 (concrete)

- Dimension of x is now 3: new dimension encodes if word is "inverter" (e.g., "not", embedding $[001]$)
- h now has dimension 5:
  - ▶ Number of positive words seen
  - ▶ Number of negative words seen
  - ▶ Was the previous word an "inverter"?
  - ▶ Was the previous word an inverted negative sentiment word (thus now positive)
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$$\mathbf{W}^{(hh)} = \begin{bmatrix} 1 & 0 & 0 & -1 & 1 \\ 0 & 1 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$
(10)

$$\left(\mathbf{W}^{(hx)}\right)^{\mathsf{T}} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$
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not joking, food is not horrible it's delicious .

$$\vec{h}_1 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{13}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{14}$$

Word 1 (not)

$$\vec{h}_1 = \mathsf{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{15}$$

$$= \mathsf{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{16}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{17}$$

Word 2 (joking,)

$$\vec{h}_2 = \mathsf{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{18}$$

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19

Word 2 (joking,)

$$\vec{h}_2 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{20}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \right) \tag{21}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{22}$$

$$\vec{h}_3 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{23}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{24}$$

Word 3 (food)

$$\vec{h}_3 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \quad (25)$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \quad (26)$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \quad (27)$$

Word 4 (is)

$$\vec{h}_4 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{28}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{29}$$

Word 4 (is)

$$\vec{h}_4 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{30}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{31}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{32}$$

$$\vec{h}_5 = \mathsf{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}}\right.$$

(33)

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}}\right)$$

(34)

$$\vec{h}_5 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{35}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{36}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{37}$$

Word 6 (horrible)

$$\vec{h}_6 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{38}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{39}$$

Word 6 (horrible)

$$\vec{h}_6 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{40}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix} \right) \tag{41}$$

$$= \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix} \tag{42}$$

Word 7 (it's)

$$\vec{h}_7 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right.$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right)$$

(43)

(44)

Word 7 (it's)

$$\vec{h}_7 = \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{45}$$

$$= \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{46}$$

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{47}$$

$$\vec{h}_8 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{48}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{49}$$

Word 8 (delicious)

$$\vec{h}_8 = \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{50}$$

$$= \text{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ 0.00 \end{bmatrix}\right) \tag{51}$$

$$= \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{52}$$

$$\vec{h}_9 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{53}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{54}$$

Word 9 (.)

$$\vec{h}_9 = \text{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{55}$$

$$= \text{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{56}$$

$$= \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{57}$$

food is crappy and not good .

Word 1 (food)

$$\vec{h}_1 = \mathsf{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{58}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{59}$$

36

Word 1 (food)

$$\vec{h}_1 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{60}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{61}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{62}$$

$$\vec{h}_2 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{63}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{64}$$

38

Word 2 (is)

$$\vec{h}_2 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{65}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{66}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{67}$$

Word 3 (crappy)

$$\vec{h}_3 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{68}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{69}$$

40

Word 3 (crappy)

$$\vec{h}_3 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{70}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \end{bmatrix} \right) \tag{71}$$

$$= \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{72}$$

Word 4 (and)

$$\vec{h}_4 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{73}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{74}$$

Word 4 (and)

$$\vec{h}_4 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{75}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{76}$$

$$= \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{77}$$

$$\vec{h}_5 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{78}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{79}$$

Word 5 (not)

$$\vec{h}_5 = \mathrm{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{80}$$

$$= \mathrm{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 1.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{81}$$

$$= \begin{bmatrix} 0.00 \\ 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{82}$$

Word 6 (good)

$$\vec{h}_6 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{83}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{84}$$

$$\vec{h}_6 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{85}$$

$$= \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}\right) \tag{86}$$

$$= \begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} \tag{87}$$

Word 7 (.)

$$\vec{h}_7 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{88}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{89}$$

Word 7 (.)

$$\vec{h}_7 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{90}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 2.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{91}$$

$$= \begin{bmatrix} 0.00 \\ 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{92}$$

everything is good and delicious .

Word 1 (everything)

$$\vec{h}_1 = \mathsf{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}}\right. \tag{93}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}}\right) \tag{94}$$

Word 1 (everything)

$$\vec{h}_1 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{95}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{96}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{97}$$

Word 2 (is)

$$\vec{h}_2 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{98}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{99}$$

Word 2 (is)

$$\vec{h}_2 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{100}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{101}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{102}$$

Word 3 (good)

$$\vec{h}_3 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{103}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{104}$$

Word 3 (good)

$$\vec{h}_3 = \mathsf{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{105}$$

$$= \mathsf{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ 0.00 \end{bmatrix}\right) \tag{106}$$

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{107}$$

Word 4 (and)

$$\vec{h}_4 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right.$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right)$$

(108)

(109)

Word 4 (and)

$$\vec{h}_4 = \mathsf{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{110}$$

$$= \mathsf{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{111}$$

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{112}$$

Word 5 (delicious)

$$\vec{h}_5 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}}\right. \tag{113}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}}\right) \tag{114}$$

Word 5 (delicious)

$$\vec{h}_5 = \mathsf{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{115}$$

$$= \mathsf{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ 0.00 \end{bmatrix} \right) \tag{116}$$

$$= \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{117}$$

Word 6 (.)

$$\vec{h}_6 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right. \tag{118}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{119}$$

Word 6 (.)

$$\vec{h}_6 = \text{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{120}$$

$$= \text{ReLU}\left(\begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{121}$$

$$= \begin{bmatrix} 2.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{122}$$

food is delicious but crappy .

Word 1 (food)

$$\vec{h}_1 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)} \vec{h}_{t-1}} \right.$$

(123)

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)} \vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right)$$

(124)

Word 1 (food)

$$\vec{h}_1 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{125}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{126}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{127}$$

$$\vec{h}_2 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}}\right. \tag{128}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}}\right) \tag{129}$$

Word 2 (is)

$$\vec{h}_2 = \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{130}$$

$$= \text{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{131}$$

$$= \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{132}$$

Word 3 (delicious)

$$\vec{h}_3 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{133}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{134}$$

Word 3 (delicious)

$$\vec{h}_3 = \mathsf{ReLU}\left(\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 1.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \qquad (135)$$

$$= \mathsf{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ 0.00 \end{bmatrix}\right) \qquad (136)$$

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \qquad (137)$$

Word 4 (but)

$$\vec{h}_4 = \text{ReLU} \left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{138}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{139}$$

Word 4 (but)

$$\vec{h}_4 = \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{140}$$

$$= \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{141}$$

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{142}$$

Word 5 (crappy)

$$\vec{h}_5 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}}\right. \tag{143}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}}\right) \tag{144}$$

Word 5 (crappy)

$$\vec{h}_5 = \mathrm{ReLU}\left(\begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}\right) \tag{145}$$

$$= \mathrm{ReLU}\left(\begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ -1.00 \end{bmatrix}\right) \tag{146}$$

$$= \begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{147}$$

Word 6 (.)

$$\vec{h}_6 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{148}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{149}$$

Word 6 (.)

$$\vec{h}_6 = \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} + \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{150}$$

$$= \text{ReLU}\left(\begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix} \right) \tag{151}$$

$$= \begin{bmatrix} 1.00 \\ 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{152}$$

Still not a good RNN!

- Unhandled cases
- Fragile

Still not a good RNN!

- Unhandled cases
- Fragile
- Because you should <u>learn</u> RNNs from data