Sequence Models

NLP: Jordan Boyd-Graber

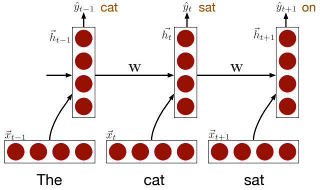
University of Maryland

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

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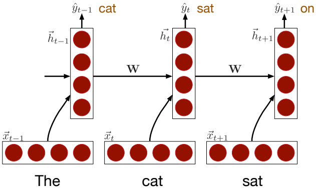


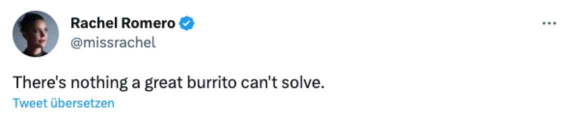
- Or using learned representation (*a la* Word2Vec)
- But today, sentiment analysis


CHIPOTLE MEXICAN GRILL
FOR YOUR CHANCE TO WIN
FREE BURRITOS FOR A YEAR,
TWEET A LOVE HAIKU
POST ON FEB. 7TH. THE HAIKU WITH THE MOST RETWEETS THAT DAY WINS.

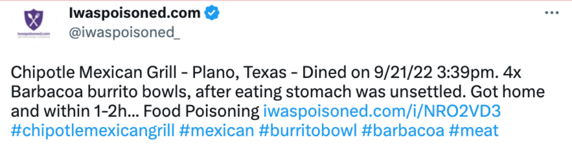

WELCOME TO
NEW WEST FEST
Open FOR BREAKFAST
illegal pete's
10-6
320

Sentiment Analysis

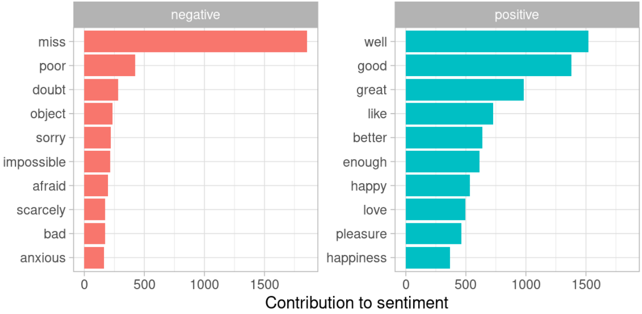
Positive Sentiment



Negative Sentiment



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


123 FAKE ST.
POLICE

What goes into a Recurrent Neural Network?

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

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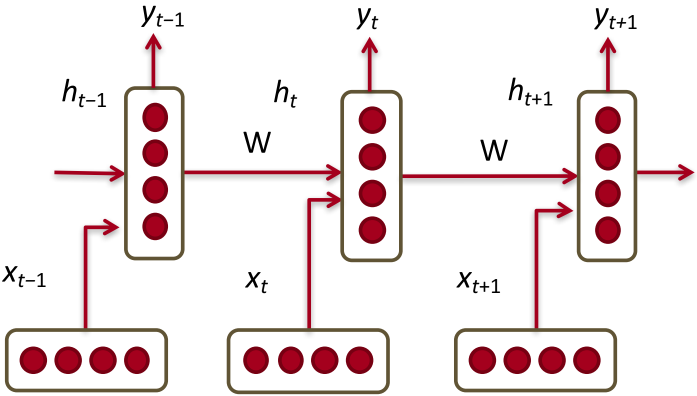
$$e[\text{"cromulent"}] = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (1)$$

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

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

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)

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

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

$$(6)$$

- 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	$x_1^\intercal = [00]$		
movie	$x_2^\intercal = [00]$		
is	$x_3^\intercal = [00]$		
an	$x_4^\intercal = [00]$		
exquisite	$x_5^\intercal = [10]$		
masterpiece	$x_6^\intercal = [10]$		
despite	$x_7^\intercal = [00]$		
the	$x_8^\intercal = [00]$		
questionable	$x_9^\intercal = [01]$		
title	$x_{10}^\intercal = [00]$		

Example

Input Token	Input	Hidden	Output
This	$x_1^\intercal = [0 0]$	$h_1^\intercal = [0 0]$	
movie	$x_2^\intercal = [0 0]$	$h_2^\intercal = [0 0]$	
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an	$x_4^\intercal = [0 0]$	$h_4^\intercal = [0 0]$	
exquisite	$x_5^\intercal = [1 0]$	$h_5^\intercal = [1 0]$	
masterpiece	$x_6^\intercal = [1 0]$	$h_6^\intercal = [2 0]$	
despite	$x_7^\intercal = [0 0]$	$h_7^\intercal = [2 0]$	
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questionable	$x_9^\intercal = [0 1]$	$h_9^\intercal = [2 1]$	
title	$x_{10}^\intercal = [0 0]$	$h_{10}^\intercal = [2 1]$	

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is	$x_3^\intercal = [00]$	$h_3^\intercal = [00]$	$y_3 = 0$
an	$x_4^\intercal = [00]$	$h_4^\intercal = [00]$	$y_4 = 0$
exquisite	$x_5^\intercal = [10]$	$h_5^\intercal = [10]$	$y_5 = 1$
masterpiece	$x_6^\intercal = [10]$	$h_6^\intercal = [20]$	$y_6 = 2$
despite	$x_7^\intercal = [00]$	$h_7^\intercal = [20]$	$y_7 = 2$
the	$x_8^\intercal = [00]$	$h_8^\intercal = [20]$	$y_8 = 2$
questionable	$x_9^\intercal = [01]$	$h_9^\intercal = [21]$	$y_9 = 1$
title	$x_{10}^\intercal = [00]$	$h_{10}^\intercal = [21]$	$y_{10} = 1$

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This doesn't actually use the sequence!

So let's look at inverting sentiment!


NOT BAD

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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$$\mathbf{W}^{(hh)} = \begin{bmatrix} 1 & 0 & 0 & -1 & 1 \\ 0 & 1 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{10}$$

$$\left(\mathbf{W}^{(hx)}\right)^{\mathsf{T}} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{11}$$

$$\vec{b}^{(h)} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -1 \\ -1 \end{bmatrix} \tag{12}$$

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Example Sentence

not joking, food is not horrible it’s delicious .

Word 1 (not)

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

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

Word 1 (not)

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

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

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

Word 2 (joking,)

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

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{19}$$

Word 2 (joking,)

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

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

Word 3 (food)

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

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

Word 3 (food)

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

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

$$= \begin{bmatrix}0.00\\0.00\\0.00\\0.00\\0.00\end{bmatrix} \tag{27}$$

Word 4 (is)

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

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

Word 4 (is)

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

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

$$= \begin{bmatrix}0.00\\0.00\\0.00\\0.00\\0.00\end{bmatrix} \quad (32)$$

Word 5 (not)

$$\vec{h}_5 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{33}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 1.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{34}$$

Word 5 (not)

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

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

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

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)

$$\vec{h}_7 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 1.00 \\ 0.00 \\ 1.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{43}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{44}$$

Word 7 (it's)

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

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

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

Word 8 (delicious)

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

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

Word 8 (delicious)

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

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

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

Word 9 (.)

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

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

Word 9 (.)

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

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

$$= \begin{bmatrix}2.00\\0.00\\0.00\\0.00\\0.00\end{bmatrix} \quad (57)$$

Example Sentence

food is crappy and not good .

Word 1 (food)

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

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

Word 1 (food)

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

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

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

Word 2 (is)

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

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

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)

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

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

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)

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

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

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

Word 5 (not)

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

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

Word 5 (not)

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

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

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

Word 6 (good)

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

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

Word 6 (good)

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

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

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

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 (.)

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

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

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

Example Sentence

everything is good and delicious .

Word 1 (everything)

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

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

Word 1 (everything)

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

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

$$= \begin{bmatrix}0.00\\0.00\\0.00\\0.00\\0.00\end{bmatrix} \quad (97)$$

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)

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

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

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

Word 4 (and)

$$\vec{h}_4 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{108}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{109}$$

Word 4 (and)

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

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

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

Word 5 (delicious)

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

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

Word 5 (delicious)

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

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

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

Word 6 (.)

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

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

Word 6 (.)

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

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

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

Example Sentence

food is delicious but crappy .

Word 1 (food)

$$\vec{h}_1 = \text{ReLU}\left(\underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 & 1.00 & -1.00 \\ 0.00 & 1.00 & 0.00 & -1.00 & 1.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hh)}\vec{h}_{t-1}} \right. \tag{123}$$

$$\left. + \underbrace{\begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 1.00 \\ 0.00 & 1.00 & 0.00 \\ 1.00 & 0.00 & 0.00 \end{bmatrix} \begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \end{bmatrix}}_{\mathbf{W}^{(hx)}\vec{x}_t} + \underbrace{\begin{bmatrix} 0.00 \\ 0.00 \\ 0.00 \\ -1.00 \\ -1.00 \end{bmatrix}}_{\vec{b}} \right) \tag{124}$$

Word 1 (food)

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

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

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

Word 2 (is)

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

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

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)

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

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

$$= \begin{bmatrix} 1.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \tag{137}$$

Word 4 (but)

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

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

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)

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

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

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

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 learn RNNs from data